Environment International 120 (2018) 181–198

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

# Associations between maternal residential proximity to air emissions from industrial facilities and low birth weight in Texas, USA

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ARTICLE INFO

Handling Editor: Marti Nadal

*Keywords:*
Air pollution
Toxic Release Inventory (TRI) chemicals
Low birth weight (LBW)
Exposure assessment
GIS
Spatial analysis
Health

ABSTRACT

*Background:* Most previous studies examining associations between maternal exposures to air pollutants during pregnancy and low birth weight (LBW) in offspring focused on criteria air pollutants ($PM_{2.5}$, $PM_{10}$, $O_3$, $NO_2$, $SO_2$, CO, and Pb). The relationship between non-criteria air pollutants and LBW is understudied and requires greater coverage.

*Objectives:* This study investigated associations between maternal residential exposure to industrial air pollutants during pregnancy and LBW in offspring.

*Methods:* This study used a case-control study design that included 94,106 term LBW cases and 376,424 controls. It covered 78 air pollutants common to both the Toxics Release Inventory (TRI) and ground air quality monitoring databases in Texas during 1996–2008. A modified version of the Emission Weighted Proximity Model (EWPM), calibrated with ground monitoring data, was used to estimate maternal residential exposure to industrial air pollutants during pregnancy. Binary logistic regression analyses were performed to calculate odds ratios (ORs) reflecting the associations of maternal exposure to industrial air pollutants and LBW in offspring, adjusted for child's sex, gestational weeks, maternal age, education, race/ethnicity, marital status, prenatal care, tobacco use during pregnancy, public health region of maternal residence, and year of birth. In addition, the Bonferroni correction for multiple comparisons was applied to the results of logistic regression analysis.

*Results:* Relative to the non-exposed reference group, maternal residential exposure to benzene (adjusted odds ratio (aOR) 1.06, 95% confidence interval (CI) 1.04, 1.08), benzo(*g,h,i*)perylene (aOR 1.04, 95% CI 1.02, 1.07), cumene (aOR 1.05, 95% CI 1.03, 1.07), cyclohexane (aOR 1.04, 95% CI 1.02, 1.07), dichloromethane (aOR 1.04, 95% CI 1.03, 1.07), ethylbenzene (aOR 1.05, 95% CI 1.03, 1.06), ethylene (aOR 1.06, 95% CI 1.03, 1.09), mercury (aOR 1.04, 95% CI 1.02, 1.07), naphthalene (aOR 1.03, 95% CI 1.01, 1.05), *n*-hexane (aOR 1.06, 95% CI 1.04, 1.08), propylene (aOR 1.06, 95% CI 1.03, 1.10), styrene (aOR 1.06, 95% CI 1.04, 1.08), toluene (aOR 1.05, 95% CI 1.03, 1.07), and zinc (fume or dust) (aOR 1.10, 95% CI 1.06, 1.13) was found to have significantly higher odds of LBW in offspring. When the estimated exposures were categorized into four different groups (zero, low, medium, and high) in the analysis, eleven of the fourteen air pollutants, with the exception of benzo (*g,h,i*)perylene, ethylene, and propylene, remained as significant risk factors.

*Conclusions:* Results indicate that maternal residential proximity to industrial facilities emitting any of the fourteen pollutants identified by this study during pregnancy may be associated with LBW in offspring. With the exception of benzene, ethylbenzene, toluene, and zinc, the rest of the fourteen air pollutants are identified as LBW risk factors for the first time by this study. Further epidemiological, biological, and toxicological studies are suggested to verify the findings from this study.

## 1. Introduction

Low birth weight (LBW), which is defined as a newborn whose weight is < 2500 g (or 5.5 lb) at birth (WHO, 1992), is an important predictor of infants' health. Compared to normal-weight infants, LBW infants may have higher risks of mortality and/or morbidity in childhood (McCormick, 1985; McIntire et al., 1999; Watkins et al., 2016), delayed motor and social development (Hediger et al., 2002), learning

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https://doi.org/10.1016/j.envint.2018.07.045
Received 6 March 2018; Received in revised form 29 July 2018; Accepted 29 July 2018

disabilities (Litt et al., 2005), type II diabetes (Whincup et al., 2008), stroke (Lawlor et al., 2005), and other adult chronic diseases (Joseph and Kramer, 1996). LBW births accounted for an estimated 2.6% of live term singleton births in the United States (U.S.) during 2000–2015, with yearly LBW rates being similar from year to year (U.S. CDC, 2018).

Four major categories of risk factors for LBW are genetics, maternal characteristics and behaviors (mother's age, smoking, and drinking status), socioeconomic factors (marriage status, income level, educational level, stress, and domestic violence), and exposure to environmental risk factors such as air pollution (U.S. CDC, 2012; Valero De Bernabé et al., 2004; Li et al., 2017; Ritz and Wilhelm, 2008; Shah et al., 2011; Srám et al., 2005). Since the mid-1990s, studies from different countries have suggested that maternal exposure to ambient air pollution (AAP) might interfere with weight gain in fetuses and cause LBW in offspring (Ebisu et al., 2008; Madsen et al., 2010; Mannes et al., 2005; Medeiros and Gouveia, 2005; Parker and Woodruff, 2008; Stankovic et al., 2011; Yorifuji et al., 2013).

Air pollutants are categorized into: (1) six criteria air pollutants (CAPs) - particulate matter ($PM_{2.5}$, $PM_{10}$), ozone ($O_3$), nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$), carbon monoxide (CO), and lead (Pb), as designated by the Clean Air Act and subsequent amendments (U.S. EPA, 2017) - and CAPs-related air pollutants, and (2) other air pollutants (non-criteria air pollutants), such as hazardous air pollutants (HAPs) and volatile organic compounds (VOCs). Based on the records from the database of Web of Science from 1904 to 2017 (Table 1), most of the studies on the topic reported in the literature focused on CAPs (Wilhelm et al., 2012).

A significant number (430) of studies examined the impact of the six common CAPs on LBW. For example, Bell et al. (2007) discovered that even low-level exposure to CO during the first and third trimesters might increase the risk of LBW, Estarlich et al. (2011) showed that maternal exposure to $NO_2$ was related to decreased birth weight, and Xu et al. (2011) found that $PM_{10}$ exposure during pregnancy was associated with increased LBW levels. In addition to the CAPs, there were also studies on CAPs-related air pollutants, including black carbon (Brauer and Lencar, 2008; Paciorek, 2010), black smoke (Pearce et al., 2012; Stankovic et al., 2011), and total suspended particle (Bobak, 2000; Lee et al., 2002; Wang et al., 1997), among others. These air pollutants were either components or combinations of the CAPs.

Among these published studies, only 40 had a focus on examining the impact of non-criteria air pollutants on LBW. The insufficient number of these studies is likely due to a lack of air monitoring data covering non-criteria pollutants. The monitoring networks of CAPs have finer sampling resolutions and more extensive geographic coverages than those of non-criteria air pollutants. These 40 studies only covered 18 non-criteria air pollutants. Most studies only investigated the impact of BTEX (Benzene, Toluene, Ethylbenzene, and Xylene) and PAHs (Polycyclic Aromatic Hydrocarbons) on LBW (Table 1). For example, Slama et al. (2009) found that maternal exposure to airborne benzene was associated with decrease in birth weight. Aguilera et al. (2009) linked exposure to BTEX with reduced birth weight. Jedrychowski et al. (2017) concluded that PAH had a significant negative impact on birth weight. However, the 18 studied air pollutants were only a small portion of the non-criteria air pollutants released into the air annually. For example, the U.S. Environmental Protection Agency (U.S. EPA) Toxic Release Inventory (TRI) program maintains data about air emissions of over 650 chemicals (TRI chemicals) from industrial facilities in the U.S., of which 449 have been recorded in Texas. All these TRI chemicals are non-criteria air pollutants and some of them may have adverse effects on birth weight (Aguilera et al., 2009; Gladen et al., 2000; Slama et al., 2009). The impact of most of these chemicals on LBW has not been investigated.

This study examined the associations between maternal exposure to TRI chemicals during pregnancy and LBW in offspring using a case-control study design through the analysis of a large georeferenced dataset in Texas over a thirteen-year period from 1996 to 2008. A total of 94,106 term LBW cases and 376,424 controls (non-LBW births) were examined. The chemicals examined included 78 chemicals common to both the TRI databases in Texas and the databases containing ground air quality monitoring data collected by the Texas Commission on Environmental Quality (TCEQ) during the study period. In addition to the large number of air pollutants covered by this study, a significant improvement of this study over previous studies is the use of ground monitoring data to calibrate the model used for exposure assessment.

## 2. Data and methods

### 2.1. Birth data

Birth certificate data for all registered births in Texas from 1996 to 2008 were obtained from the Center for Health Statistics in the Texas Department of State Health Services (DSHS). Variables in each birth certificate record included location of maternal residence (geographic coordinates of the maternal address); birth information (birth weight, birth year, plurality, child's sex, and gestational age in weeks); mother's characteristics (age, race/ethnicity, education, marital status, prenatal care, and tobacco use during pregnancy); and father's characteristics (age, race/ethnicity, and education). We followed the approaches used by other researchers and excluded births with weight < 1000 g or > 5500 g (0.1%) (Alexander et al., 1996; Bell et al., 2007; Habermann and Gouveia, 2014; Ritz and Yu, 1999). In addition, births with gestational age > 44 weeks or < 37 weeks (17.8%), plural deliveries (2.7%), or births with incomplete location information (10.9%) were excluded. Also omitted were births that were given by non-Texas residents or occurred outside of Texas (0.2%). LBW cases were defined as births weighted < 2500 g. Control births, defined as births weighted greater than or equal to 2500 g, were randomly selected from the birth certificate database in Texas and frequency-matched to cases by year of birth (1996–2008), at a ratio of four controls for each case.

### 2.2. Air emission data of TRI facilities

The air emission data were obtained from the U.S. EPA TRI program. The TRI program is a mandatory program established by Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA) to support and promote emergency planning and to provide the public with information about releases of toxic chemicals in their communities (U.S. EPA, 2013). The TRI program requires U.S. facilities in different industrial sectors to annually report information about their locations, types of chemicals released, and estimated quantity of a chemical released into the environment. This study selected air emission data in Texas from the national TRI databases. During 1996–2008, there were a total of 449 chemicals released into the air by Texas industrial facilities. The number of reporting industrial facilities in Texas ranged from 1286 to 1635 in each of the 13 years. This study used geocoded facility addresses maintained at Texas State University. The details of the geocoding process are provided elsewhere (Zhan et al., 2015). On average, 89.66% of the TRI facilities were successfully geocoded during the thirteen-year period (Fig. 1a). More details of the TRI air emission data can be found in an EPA project report (Zhan et al., 2015).

### 2.3. Air quality monitoring data

The air quality monitoring data were obtained from the Texas Air Monitoring Information System (TAMIS) database maintained by the TCEQ (2017a). This study selected data from all 331 active monitoring sites during 1996–2008 (Fig. 1b). Most of the air monitoring sites were located in urban areas, especially in the Dallas-Fort Worth, El Paso, and Houston areas. Each record in the monitoring database contained 367 variables measuring the 24-hour integrated ambient concentrations of