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Characterization of traffic-related air pollutant metrics at four schools in El Paso, Texas, USA: Implications for exposure assessment and siting schools in urban areas

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HIGHLIGHTS

- Study characterizing traffic air pollutants at four schools in El Paso, Texas, USA.
- Paired indoor–outdoor sampling of $PM_{2.5}$, $PM_{10-2.5}$, BC, VOCs and NO_2 for 13 weeks.
- Three schools in high traffic exposure zones and one in low traffic exposure zone.
- Spatially resolved traffic environmental indicators used in various exposure settings.
- Substantial intra-urban spatio-temporal heterogeneity in pollutant concentrations observed.

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ABSTRACT

Children spend substantial amount of time within school microenvironments; therefore, assessing school-based exposures is essential for characterizing and preventing children's health risks to air pollutants. Indeed, the importance of characterizing children's exposures in schools is recognized by the US Environmental Protection Agency's recent initiative to promote outdoor air monitoring networks near schools. As part of a health effects study investigating the impact of traffic-related air pollution on asthmatic children along the US–Mexico border, this research examines children's exposures to, and spatio-temporal heterogeneity in concentrations of, traffic-related air pollutants at four elementary schools in El Paso, Texas. Three schools were located in an area of high traffic density and one school in an area of low traffic density. Paired indoor and outdoor concentrations of 48-h fine and coarse particulate matter ($PM_{2.5}$ and $PM_{10-2.5}$), 48-h black carbon (BC), 96-h nitrogen dioxide (NO_2), and 96-h volatile organic compounds (VOCs) were measured for 13 weeks at each school. Outdoor concentrations of PM, NO_2, BC, and BTEX (benzene, toluene, ethylbenzene, m,p-xylene, o-xylene) compounds were similar among the three schools in the high-traffic zone in contrast to the school in the low-traffic zone. Results from this study and previous studies in this region corroborate the fact that PM pollution in El Paso is dominated by coarse PM ($PM_{10-2.5}$) and fine fraction ($PM_{2.5}$) accounts for only 25–30% of the total PM mass in PM_{10}. BTEX species and BC are better surrogates for traffic air pollution in this region. Correlation analyses indicate a range of association between indoor and outdoor pollutant concentrations due to uncontrollable factors like student foot traffic and varying building and ventilation configurations across the four schools. Results suggest the need of micro-scale monitoring for children's exposure assessment, which may not be adequately characterized by the measurements from a centralized monitoring site.

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1. Introduction

Traffic air pollution and associated health effects have elicited considerable interest in the exposure science and epidemiologic community (HEI, 2010). Many of these studies assess the exposures to traffic air pollutants, especially $PM_{2.5}$ and NO_2, by employing air pollution data from central ambient monitoring sites (Dockery et al., 1993; Pope et al., 2002). These sites may provide reasonable surrogates for short and long-term exposure to spatially homogenous air pollutants. However, traffic air pollutants may exhibit strong spatial gradients and personal exposures to these pollutants may, thus, vary depending on traffic density and, proximity to roadways (Zhu et al., 2003). Central monitoring sites, therefore, may not be an appropriate proxy for personal exposures, especially for sensitive populations like school-aged asthmatic children, leading to potential exposure misclassifications (Adgate et al., 2002; Kousa et al., 2002). The location of schools near busy traffic intersections and freeways can also result in high-traffic pollution exposures for children attending these schools. A study conducted by Green et al. (2004), for example, showed that one in eight California students (721,363 children) attend a school that records more than 25,000 vehicle trips per day on adjacent roads. Furthermore, researchers have documented higher levels of air pollutants inside classrooms and residences than the corresponding outdoor levels due to human presence, occupancy rates and patterns (Blondeau et al., 2005; Braniš et al., 2009).

Children, on average, spend around eight hours in schools per day, of which a significant amount of time is spent in classrooms. Classroom exposures can be different from ambient exposures. Understanding the contribution of traffic sources within the classroom remains challenging due to the lack of a single traffic metric, varying pollutant concentration gradients, and co-varying distributions of identical pollutants from non-traffic point and area sources. This situation is especially exacerbated in a US–Mexico border city like El Paso, Texas, due to the region's arid weather, the surrounding desert, frequent temperature inversions, heavy daily border traffic, and its aged, poorly maintained vehicle fleet. The impact of exposure to these traffic emissions, particularly on asthmatic children, is poorly understood although small-scale, pilot-type studies have been previously conducted in this region (Gonzales et al., 2005; Holguin et al., 2007).

We conducted a binational pilot study characterizing traffic-related air pollution (Raysoni et al., 2011) and investigating the corresponding acute health response for a pediatric asthma cohort living in high- and low-traffic density areas in the twin cities of El Paso and Ciudad Juarez in 2008 (Sarnat et al., 2012). We evaluated the ability of several potential environmental health indicators of traffic-related pollution to reflect the changes in the study cohort's respiratory health. The observed health associations varied substantially depending on the choice of monitoring sites and the microenvironment with exposure metrics from ambient monitoring stations located close to or directly outside the schools providing the best measure of children's health response. Correspondingly, we posited that single-site monitoring may be inadequate for characterizing pollutant exposures and corresponding environmental health effects and additional information is required to determine the consistency of these results for other heterogeneously distributed pollutants.

In 2010, we conducted a follow-up panel-based exposure and health assessment study at four El Paso elementary schools with the specific aims to 1) measure outdoor and indoor concentrations of multiple traffic-related air pollutants, especially those known to have numerous sources, at schools in high and low exposure zones; 2) identify environmental health indicators for traffic-related air pollution; and 3) examine associations between children's respiratory response and corresponding exposure metrics at these schools. The specific purpose of this paper is to characterize the traffic-related air pollutants, both outdoors and indoors, at schools located in low and high traffic exposure zones, and examine the intra-urban heterogeneity in the traffic pollutant concentrations. The results pertaining to health associations have been reported elsewhere (Greenwald et al., 2012).

2. Study design and methods

2.1. Site selection

Four elementary schools, with one in a 'low-exposure' zone (EP-A) and three in 'high-exposure' zones (EP-B, EP-C, EP-D), were selected to confirm the assumed pollutant exposure gradient and enhance the subsequent power to detect differences in pulmonary inflammatory responses within the study cohort. EP-A was located in a residential area with minimal traffic in the northeastern part of the city. EP-B was situated immediately adjacent to the Border Highway (Route 375), along the US–Mexico Border fence. Route 375 is a major arterial highway for northbound commercial trucks as well as local commuter vehicles. Fig. 1 shows the locations of the four schools as well as the Texas Commission on Environmental Quality (TCEQ) continuous air monitoring sites (CAMS). Two additional schools (EP-C and EP-D), both located within 2 miles from EP-B, were selected for air pollution monitoring because EP-C was ranked in the 1st percentile and EP-D was ranked in the 3rd percentile of most polluted schools in the U.S. in 2009 (USA Today, 2009). The locations of EP-B, EP-C, and EP-D formed a line perpendicular to the US–Mexico border and the Border Highway, thereby providing an ideal exposure gradient from the highway.

2.2. Topography and meteorology

The city of El Paso, approximately 3800 ft above sea level, is a flat desert area with a large range of mountains, which rise to over 3280 ft (1000 m). Dust storms are a common occurrence with an average of 14.5 significant dust events per year. Health consequences range from simple irritations to serious disruptive events such as increased respiratory health problems and near-zero visibility leading to increased roadway accidents and fatalities. Westerly winds prevailed for the entire region during the study period (Fig. 2), with the greatest frequency of wind speeds measured between 0.5 and 2.1 m s^{-1}.

2.3. Sampling methods

An air monitoring campaign was conducted between March 1 and June 4, 2010, with temporary suspensions during holidays, spring break and scheduled standardized test-taking. Samples of 48-h integrated PM ($PM_{2.5}$ and $PM_{10-2.5}$, BC), and 96-h integrated NO_2 and VOCs, were collected at two locations, one indoor and one outdoor, at each school. The 48-h samples were collected twice a week (Monday–Wednesday and Wednesday–Friday), and the 96-h samples were collected once a week (Monday–Friday) between 8:30 and 11:30 am. The sampling durations were designed to ensure the collection of sufficient mass for detection and analysis, to reflect children's time activity patterns at schools, and to be representative of the resolved data for air pollution epidemiology. All indoor air samplers were mounted on a sampling stand at an inconspicuous location and the noise level was muffled with noise reduction devices. Sampling in the indoor microenvironment was conducted at: a space near a teacher's work desk in a computer room (EP-A), or in the library (EP-B, EP-C, and EP-D).