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Populations potentially exposed to traffic-related air pollution in seven world cities

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ABSTRACT

Traffic-related air pollution (TRAP) likely exerts a large burden of disease globally, and in many places, traffic is increasing dramatically. The impact, however, of urban form on the portion of population potentially exposed to TRAP remains poorly understood. In this study, we estimate portions of population potentially exposed to TRAP across seven global cities of various urban forms. Data on population distributions and road networks were collected from the best available sources in each city and from remote sensing analysis. Using spatial mapping techniques, we first overlaid road buffers onto population data to estimate the portions of population potentially exposed for four plausible impact zones. Based on a most likely scenario with impacts from highways up to 300 meters and major roadways up to 50 meters, we identified that the portions of population potentially exposed for the seven cities ranged from 23 to 96%. High-income North American cities had the lowest potential exposure portions, while those in Europe had the highest. Second, we adjusted exposure zone concentration levels based on a literature suggested multiplier for each city using corresponding background concentrations. Though Beijing and Mexico City did not have the highest portion of population exposure, those in their exposure zones had the highest levels of exposure. For all seven cities, the portion of population potentially exposed was positively correlated with roadway density and, to a lesser extent, with population density. These analyses suggest that urban form may influence the portion of population exposed to TRAP and vehicle emissions and other factors may influence the exposure levels. Greater understanding of urban form and other factors influencing potential exposure to TRAP may help inform interventions that protect public health.

1. Introduction

Motor vehicle emissions are major contributors to urban air pollution (HEI, 2010). Epidemiological evidence identifies traffic-related air pollution (TRAP) as a risk factor for adverse health outcomes, including preterm birth (prior to 37 weeks of pregnancy) and low birth weight (live born infant of ≤2500 g) (Lee et al., 2008; Ritz and Yu, 1999; Wilhelm et al., 2011), respiratory disease incidence and exacerbation (Jerrett and Finkelstein, 2005; Spirić et al., 2012; Zhu et al., 2012), cardiovascular disease (Beelen et al., 2014; Jerrett et al., 2013; Langrish et al., 2012; Raaschou-Nielsen et al., 2012), and premature mortality (Jerrett et al., 2009, 2011). The International Agency for Research on Cancer recently declared TRAP as a Group 1 carcinogen, i.e., a causal agent in human carcinogenesis. The main pollutants of health concern emitted by vehicles are nitrogen oxides (nitric oxide — NO, nitrogen dioxide — NO_2 and nitrogen oxides — NO_X), fine particulate matter, ultrafine to data acquired separately for the seven individual cities, diesel soot, carbon monoxide, transition metals, and a variety of other gas- and particle-phase air contaminants (Kampa and Castanas, 2008).

Spatial considerations strongly influence the relationship between vehicle emissions and resulting population exposures to primary air pollution. Unlike other major sources of urban air pollution, vehicle emissions occur at ground level and in proximity to large human populations. At the urban scale, a key consequence of this spatial pattern is that vehicle emissions have especially high intake fraction: each unit of emissions leads to relatively high population exposure (Apte et al., 2012; Marshall et al., 2005). At finer spatial scales, concentrations of key TRAP pollutants are sharply elevated over urban background levels near major roads and highways, and decline back to ambient levels over characteristic distances of 50–500 m in most cases, although some studies have identified much larger influence zones depending on meteorology and topology (Gilbert et al., 2005; Hu et al., 2009; Su et al., 2009a). The unequal spatial distribution of pollution raises health and

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equity concerns, especially for populations living near major roads (Finkelstein et al., 2005; Pastor et al., 2005; Su et al., 2009b, 2012). A substantial and growing body of evidence suggests that populations near roadways experience health risks in excess of those exposed at urban background levels (Brugge et al., 2007; Finkelstein et al., 2005; Hoek et al., 2002; Peters et al., 2004).

Over the past decade, sustained attention has been devoted to characterizing and understanding near-roadway air pollutant dynamics (HEI, 2010; Karner et al., 2010; Kumar et al., 2011; Zhu et al., 2002). Comparatively less is understood about other parameters that govern population exposure to near-roadway air pollution, such as the size of the population exposed near roadways. Based on a synthesis of the best available evidence, the Health Effects Institute (HEI, 2010) identified “exposure zones” within a range of up to 500 m from a highway or 300 m from a major road as the area most highly impacted by traffic emissions, and estimated that 30% to 45% of people living in large North American cities live within such zones. Urban form varies substantially among cities, countries, and world regions in ways that may affect population exposure to traffic emissions. For example, population densities in European and Asian cities are typically higher than in North America (Muller, 2004). Previous work has highlighted the effect of population density on exposures to vehicle emissions in urban settings (Apte et al., 2012; Marshall et al., 2005). Here, we aim to illustrate how differences in urban form affect exposure in near-roadway environments in seven global cities. We focus on one useful proxy of population exposure to traffic emissions, the fraction of urban population that resides within the “exposure zone” of main roadways. Because vehicle emissions and other factors such as type of vehicles, fuel used and traffic activity also contribute to the levels of concentration in an exposure zone, rather than assuming all the highways and major roadways in a distance exposure zone have an equal impact across the seven cities, we recalculated pollutant concentrations of NO_2 — a pollutant mainly contributed by traffic — for the seven city exposure zones using a multiplier for estimating corresponding above background concentration (Karner et al., 2010). To estimate these exposure parameters, we combine remotely-sensed satellite imagery with local data on urban form, population and road networks. The seven cities examined included three North American (Toronto, Canada; Los Angeles, USA; and Mexico City, Mexico), two Asian (Beijing, China; and New Delhi, India) and two European cities (Paris, France; and Barcelona, Spain) from developed (Canada, USA, France, and Spain) and developing (Mexico, China, and India) nations.

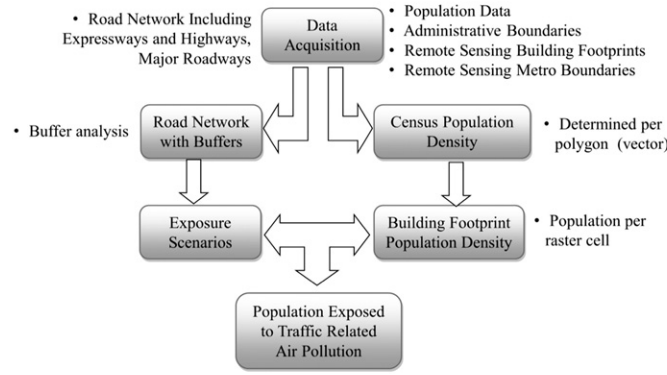
2. Materials and methods

2.1. Overview of the methods

The seven cities considered here span three continents, as well as a wide range of socioeconomic and environmental conditions. Spatial data were collected from local contacts including population (e.g. census tracts, wards), road networks, pollutant NO_2 concentrations, traffic volumes and administrative boundaries. In addition, remote sensing data were used to derive building footprints and to define metropolitan agglomerations. Population data were consolidated to the remote sensing building footprints for all seven cities. Given the availability of data for a city, we created two extents of analysis: one with city political boundaries and another with urban boundaries estimated from remote sensing techniques (Schneider et al., 2009). Scenarios of exposure zones for traffic-related air pollution were based on HEI research findings (HEI, 2010). Scheme 1 displays the analysis procedure.

2.2. Data sources

For the purpose of this analysis, we defined “highways” as all main transportation thoroughfares including highways and limited-access expressways. “Major roadways” were defined as transportation thoroughfares connecting highways and limited access expressways. We list the data sources for road networks and census populations used in the study in the following sequence: cities in North America, Asia, and Europe.



Scheme 1. Population exposure analysis process.

2.2.1. Los Angeles, USA

We used Dynamap data from TeleAtlas (Global Crossroads, Boston, MA) for 2000 as the base road network configuration. The highway category was based on combining two categories from the Dynamap database: (1) primary roadways without limited access (Feature Class Code — FCC A1); and (2) primary roadways with limited-access or state highways (FCC A2). Major roadways were created from the Dynamap secondary and connecting roadway data category (FCC A3). The population data and corresponding boundary files were at the census tract level from U.S. Census Bureau for 2000.

2.2.2. Toronto, Canada

The road network and building footprint data for Toronto were acquired from DMTI Spatial (Markham, Ontario) for 2005. The cartographic road network classification includes expressway, primary highway, secondary highway, major roadways, and local roadways. Expressways and primary and secondary highways were reclassified to our highway category. For major roadways we used the existing classification. The population data were provided at the block group level from Statistics Canada E-Stat (2002) for 2001.

2.2.3. Mexico City, Mexico

We acquired comprehensive cartographic road network data for Mexico City from the National Institute of Statistics and Geography (INEGI). This dataset classified each road on the network according to the number of lanes, roadway speed limits, road category, whether it belonged to a toll or a free road, and whether it was administrated by the federal or state government. The road network data, however, did not include specific categories for highways or major roadways; thus, we used Google Earth as a guide to identify all highways and major roadways in the city based on road width, likely functional use, and classifications by Google. We also sought suggestions from collaborators in Mexico and from graduate students in our lab who were familiar with the city's geography to aid in the classification process.

For population data, we collected Basic Geostatistical Area (AGEB) level data for 2005. In total, there were 8.54 million people in Mexico City. The attribute data were provided by INEGI. We linked the population attribute data to the spatial AGEB-level data.

2.2.4. Beijing, China

China's road network, from political and management purposes, is classified as either expressway or national, provincial, county or city/village roadway. We acquired the Beijing road network and building footprint data from SinoMaps Press for 2010. To be consistent with the road network classification in other cities, we collapsed expressway, national, provincial and county-level roadways into the highway category. The