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Spatial resolution requirements for traffic-related air pollutant exposure evaluations

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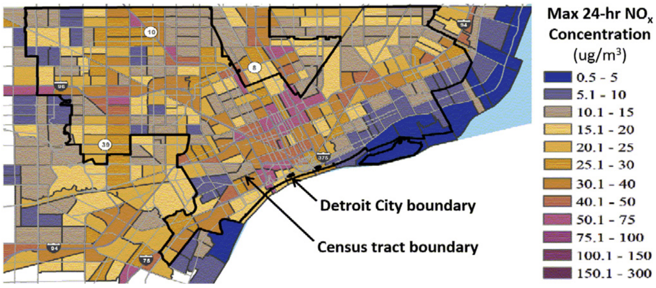
HIGHLIGHTS

- Dispersion models can estimate traffic-related air pollutants at the urban scale.
- High spatial resolution is needed to minimize exposure misclassification.
- Exposures may be overestimated by averaging across census tracts or ZIP codes.
- Raster or inverse distance-weighted interpolations are preferred.
- Interpolation distances near major roads should not exceed 40–100 m.

GRAPHICAL ABSTRACT



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ABSTRACT

Vehicle emissions represent one of the most important air pollution sources in most urban areas, and elevated concentrations of pollutants found near major roads have been associated with many adverse health impacts. To understand these impacts, exposure estimates should reflect the spatial and temporal patterns observed for traffic-related air pollutants. This paper evaluates the spatial resolution and zonal systems required to estimate accurately intraurban and near-road exposures of traffic-related air pollutants. The analyses use the detailed information assembled for a large (800 km^2) area centered on Detroit, Michigan, USA. Concentrations of nitrogen oxides (NO_x) due to vehicle emissions were estimated using hourly traffic volumes and speeds on 9700 links representing all but minor roads in the city, the MOVES2010 emission model, the RLINE dispersion model, local meteorological data, a temporal resolution of 1 h, and spatial resolution as low as 10 m. Model estimates were joined with the corresponding shape files to estimate residential exposures for 700,000 individuals at property parcel, census block, census tract, and ZIP code levels. We evaluate joining methods, the spatial resolution needed to meet specific error criteria, and the extent of exposure misclassification. To portray traffic-related air pollutant exposure, raster or inverse distance-weighted interpolations are superior to nearest neighbor approaches, and interpolations between receptors and points of interest should not exceed about 40 m near major roads, and 100 m at larger distances. For census tracts and ZIP codes, average exposures are overestimated since few individuals live very near major roads, the range of concentrations is compressed, most exposures are misclassified, and high concentrations near roads are entirely omitted. While smaller zones improve performance considerably, even block-level data can misclassify many individuals. To estimate exposures and impacts of traffic-related pollutants accurately, data should be geocoded or estimated at the most-resolved spatial level; census tract and larger zones have little if any ability to represent intraurban variation in traffic-related air pollutant concentrations. These results are

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based on one of the most comprehensive intraurban modeling studies in the literature and results are robust. Additional recommendations address the value of dispersion models to portray spatial and temporal variation of air pollutants in epidemiology and other studies; techniques to improve accuracy and reduce the computational burden in urban scale modeling; the necessary spatial resolution for health surveillance, demographic, and pollution data; and the consequences of low resolution data in terms of exposure misclassification.

1. Introduction

The transport sector is the largest emitter of nitrogen oxides (NO_x) and carbon monoxide (CO), and mobile sources are major sources of other pollutants, including particulate matter ($PM_{2.5}$) and volatile organic compounds (VOCs) (European Environment Agency, 2013; U.S. Environmental Protection Agency, 2013). Traffic-related air pollutants are emitted at or near ground level and mostly in urban areas where they can cause locally-elevated concentrations that have been associated with adverse health effects, e.g., exacerbation of asthma, impaired lung function, cardiovascular morbidity and mortality, adverse birth outcomes, and cognitive declines (U.S. Environmental Protection Agency, 2008; Health Effects Institute, 2010; Laumbach and Kipen, 2012). Exposure to traffic-related pollutants is widespread, occurring in numerous locations, e.g., residences, workplaces, schools, and playgrounds located near high traffic roads. Health impacts can be significant at local to global scales (Huang and Batterman, 2000; Wu and Batterman, 2006). Low income and minority individuals often live near high traffic roads, and these populations are particularly vulnerable (Tian et al., 2013) Recognizing the importance of these effects and the many people potentially affected, the number of scientific and policy investigations on traffic-related air pollutants has grown rapidly. Such investigations are conducted at project, intraurban, multicity, national and international levels, and for purposes that include exposure and risk estimation, epidemiology, health impact assessment, accountability and regulatory compliance (Molitor et al., 2007; Isakov et al., 2009; Health Effects Institute, 2010; Bell et al., 2011; Hystad et al., 2011; Lobdell et al., 2011).

Exposure to traffic-related air pollutants occurs in “on-road,” ”near-field” and “far-field” micro-environments (Batterman, 2013). On-road exposure applies to commuters, pedestrians, cyclists and workers such as police and truck drivers, who travel and work on high traffic roads, and to pedestrians, cyclists and runners. This applies to many individuals, e.g., in the US, an estimated 119 million persons commute using cars, trucks and vans, 7 million use public transportation, 4 million walk, and 0.75 million cycle, and the average one-way commute lasts 25 min (McKenzie and Melanie, 2011). The second and most widely analyzed microenvironment is the region lying within several hundred meters of major roads. Many people live, work, go to school and recreate in this near-field microenvironment, e.g., 18% of US homes are within 300 feet of a four-lane highway, railroad or airport; this increases to 22 and 25% for Hispanic and Black households, respectively (U.S. Department of Housing and Urban Development and U.S. Department of Commerce, (2011)) The far-field environment applies to areas more distant from major roads and urban areas where traffic-related emissions become part of the “urban plume”. At this scale, spatial and temporal gradients are present but blurred.

Concentrations of traffic-related air pollutants show dramatic temporal and spatial variation in on-road and near-field environments. For example, $PM_{2.5}$, ultrafine PM (currently unregulated), volatile organic compounds (VOCs), NO, and polycyclic aromatic hydrocarbons (PAHs) demonstrate steep gradients in concentrations, attaining elevated levels near and on roads, and a return to background levels at distances of roughly 150 to 200 m (Barzyk et al., 2009; Hagler et al., 2009; Hu et al., 2009; Karner et al., 2010). This variation leads to significant uncertainty in quantifying concentrations and exposures (Health Effects Institute, 2010) For example, due to their limited number and siting criteria (Wilson et al., 2005; Hystad et al., 2011), data from central ambient monitoring sites capture little of this variability. While additional information will be provided by the new near-road monitoring network for certain pollutants (e.g., NO_2) measured within 50 m of high traffic roads in the US, this network is not designed to provide spatial coverage or to estimate population exposures (Batterman, 2013). It is important to reduce the spatial and temporal errors in concentration estimates used to estimate exposures in epidemiology, health impact and environmental justice studies (Jerrett et al., 2005; Brauer, 2010; Sheppard et al., 2012). Such errors have deleterious effects, e.g., exposure misclassification can diminish the effect sizes and bias results towards the null (no-effect) in epidemiology studies, incorrectly predict risks in health impact studies, and misidentify affected populations in justice studies.

The challenge of estimating exposures of traffic-related air pollutants has been tackled by a variety of methods, e.g., simple proximity assessments, statistical land-use regression models, source-oriented models incorporating mechanistic sub-models (for emissions, dispersion, transformation, exposure), and hybrid approaches combining several approaches (Huang and Batterman, 2000; Sharma and Khare, 2001; Jerrett et al., 2005; Wilson et al., 2005; Hoek et al., 2008; Lipfert and Wyzga, 2008; Brauer, 2010; Health Effects Institute, 2010). To estimate exposures and health impacts, exposure estimates are being applied to census and other geocoded data. The use of such data with geographical information systems (GIS) has become routine, and potentially can inform policies at local to national scales (English et al., 1999; Lin and Lin, 2002; Jin and Fu, 2005). With a few exceptions, e.g., certain air pollution epidemiology studies and a small number of quantitative health impact studies, estimates of health impacts attributable to traffic-related air pollutants have used simplified large-scale box-type models that do not represent spatial gradients or short-term fluctuations in concentrations (Apte et al., 2012; Chart-asa et al., 2013). Refined and validated methods are needed to estimate exposures and better understand the burden of disease attributable to traffic-related air pollutants, and to identify susceptible populations. Indeed, the modeling system described below was developed to support an epidemiological investigation of effects of diesel exhaust emissions on the respiratory health of children (Vette et al., 2013).

1.1. Objectives

This paper evaluates spatial resolution issues involved in estimating near-field exposures of traffic-related air pollutants for epidemiological, health risk and policy applications. The analysis uses a large-scale and detailed case study centered on Detroit,