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Land use regression models as a tool for short, medium and long term exposure to traffic related air pollution

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HIGHLIGHTS

- Personal exposure of children to BC and NO_2 was assessed for different time lags.
- Exposure was determined by time-weighting concentrations at home and at school.
- Daily concentrations were calculated from seasonal land use regression models.
- Daily LUR estimates outperform concentrations observed at nearby fixed monitors.

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ABSTRACT

Background and aims: In the HEAPS (Health Effects of Air Pollution in Antwerp Schools) study the importance of traffic-related air pollution on the school and home location on children's health was assessed. 130 children (aged 6 to 12) from two schools participated in a biomonitoring study measuring oxidative stress, inflammation and cardiovascular markers.
Methods: Personal exposure of schoolchildren to black carbon (BC) and nitrogen dioxide (NO_2) was assessed using both measured and modeled concentrations. Air quality measurements were done in two seasons at approximately 50 locations, including the schools. The land use regression technique was applied to model concentrations at the children's home address and at the schools.
Results: In this paper the results of the exposure analysis are given. Concentrations measured at school 2 h before the medical examination were used for assessing health effects of short term exposure. Over two seasons, this short term BC exposure ranged from 514 ng/m^3 to 6285 ng/m^3, and for NO_2 from 11 μg/m^3 to 36 μg/m^3. An integrated exposure was determined until 10 days before the child's examination, taking into account exposures at home and at school and the time spent in each of these microenvironments. Land use regression estimates were therefore recalculated into daily concentrations by using the temporal trend observed at a fixed monitor of the official air quality network. Concentrations at the children's homes were modeled to estimate long term exposure (from 1457 ng/m^3 to 3874 ng/m^3 for BC; and from 19 μg/m^3 to 51 μg/m^3 for NO_2).
Conclusions: The land use regression technique proved to be a fast and accurate means for estimating long term and daily BC and NO_2 exposure for children living in the Antwerp area. The spatial and temporal resolution was tailored to the needs of the epidemiologists involved in this study.

1. Introduction

In developed countries, motor vehicles are a major source of air pollution and they have a substantial impact on ambient air pollution, indoor air, and personal exposures. Traffic-related air pollution is a complex mix of components and much is unknown about the toxicity of the different components (Laumbach and Kipen, 2012). Traffic emissions contribute to both primary air pollutant concentrations (e.g. BC, NOx, CO, benzene, UFP, PM, VOC) that are emitted directly from tailpipes, tires and brakes and to secondary pollutant concentrations (e.g. NO_2, O_3, secondary (in)organic aerosols) that are formed in the atmosphere from precursors (Erisman and Schaap, 2004; HEI, 2010; Int Panis, 2008; Marshall et al., 2005). When estimating the impact of traffic on ambient concentrations and exposure, most studies focus on single compounds (primary or secondary), referred to as carriers or markers, although specific health effects may not be caused by just one component but by the collective attributes of the 'cocktail' (HEI, 2010).

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Alternatively, direct measures of traffic (traffic intensity on the nearest road, road length in buffers, etc.) are used to quantify exposure to traffic-related air pollution.

Near-road exposure to traffic-related pollution is identified as a cause of important health effects. It is known that children are potentially more susceptible to PM-induced health effects compared to the general population. This is a result of several physiological factors that may lead to an increased dose per lung surface area (Sacks et al., 2011; Schwartz, 2004). Living near busy roads and the presence of truck traffic was associated with increased personal exposure of schoolchildren to traffic-related pollutants ($PM_{2.5}$, NO_2 and soot) (Janssen et al., 2001; Van Roosbroeck et al., 2006). The respiratory system is the first target organ for airborne pollutants, and exposure to traffic and traffic-related air pollutants has been linked to lung development, airway allergies and asthma in children (Gauderman et al., 2004; Gehring et al., 2010; Laumbach and Kipen, 2012; McConnell et al., 2006). Furthermore, air pollutant exposure has been linked with several oxidative stress and inflammation biomarkers in both healthy and asthmatic children (Barraza-Villarreal et al., 2008; Liu et al., 2009).

Children are mainly exposed at home, but a notable fraction of the day is spent at school. Moreover, children are at school during day hours when traffic-related air pollution is highest, and they also spent a sizeable part of their school hours doing physical activity resulting in a higher air pollutant intake (Mejía et al., 2011). Long term air pollution can be estimated at different locations by using models that take into account intra-urban variations in air pollution (Beverland et al., 2012; Jerrett et al., 2005). In recent years, the land use regression (LUR) technique has gained a lot of attention and proved to be a useful technique for assessing medium or long term outdoor air pollution exposure in cohort studies (Brauer et al., 2003; Briggs et al., 1997; Hoek et al., 2008; Raaschou-Nielsen et al., 2013). Accurate exposure assessment has been called one of the main challenges in epidemiological research; dissimilarities in pollution–health associations for different exposure models highlight the importance of detailed exposure assessment (Fenske, 2010; Yap et al., 2012). This is especially true for pollutants that are spatially heterogeneous, and less for PM_{10} or $PM_{2.5}$ (Hodas et al., 2014).

In the HEAPS-study (Health Effects of Air Pollution in Antwerp Schools) the importance of the school location on children's exposure and health was investigated in Antwerp, Belgium, with a special focus on traffic-related air pollution. More specifically, black carbon (BC) and nitrogen dioxide (NO_2) concentrations were measured and modeled. Concentration levels in the urban area of Antwerp are expected to be at the higher end of the distribution of annual average concentrations in developed countries (EEA, 2011; U.S.EPA., 2012). Due to its central location in Europe, Flanders is an important traffic hot spot in Western Europe, and it has a high share of diesel fuelled passenger cars (62% in Belgium (NIS, 2010)). In HEAPS, 130 children (6 to 12 years old) from 2 schools and living in the same urban area, participated in a biomonitoring study. In the study oxidative stress, inflammation and cardiovascular markers were measured to assess the possible health impact of the air pollutants in the living environment of the children. The measurements in exhaled air (exhaled nitric oxide), in exhaled breath condensate (pH, interleukin 1beta, 15-F_{2t} isoprostane), and in nasal mucus (interleukin-8, eosinophilic cationic protein and tryptase) are indicators for local oxidative stress and/or inflammation. They reflect short-term induced conditions in the airways, but can possibly be affected for a longer period because of chronic triggering or their role in chronic inflammation. In the same way the cardiovascular markers, blood pressure and heart beat, were assessed to explore to which extent they were affected by short or long term air pollutant exposure. The aim of the current paper is to show the results of air pollution measurements and LUR modeling as tools to assess exposure of schoolchildren. Based on a two-fold repeated one-week sampling campaign at approximately 50 subjects' home locations, the exposure at school and at home was assessed for all children in different time windows.

2. Methods

2.1. Monitoring sites

In order to develop a LUR model for the assessment of annual and short-term concentrations on all school and home locations of the schoolchildren, NO_2 and BC measurements were performed at a number of locations. Monitoring sites were selected aiming at a large variation in traffic characteristics and pollutant levels, while also being representative for the population that the final LUR model was applied to (Lebret et al., 2000; Wang et al., 2012). Therefore, all potential monitoring (home) locations were split into different categories based on available GIS data. The defined categories are based on traffic intensities and distance to the nearest road (Table 1). Street (S) locations were sites situated next to a road carrying more than 10,000 vehicles per day. Rural (R) locations were defined as being in an area of less than 2000 inhabitants/km^2 and located more than 300 m from a road with >10,000 vehicles/day. Urban background (UB) and urban traffic (UT) locations were both located in an urban area (with more than 2000 inhabitants/km^2); whereas the UB was located more than 300 m from a busy street with >10,000 vehicles/day, the UT location was within a distance of 300 m from a busy road but not directly next to this road. The 2 schools were situated 2.8 km apart, but inside the Antwerp urban area and school catchment areas partly overlapped. One school (school 1) was located next to a quiet no-through road in the vicinity of a public park, while the other school (school 2) was situated next to a major road. One extra sampling location was next to a fixed urban monitoring site ('42R801') of the AQ monitoring network (shown on Fig. 1). Sampling was performed at this location during the entire monitoring campaign. In total 55 sites were selected to measure BC and NO_2 (Table 1; Fig. 1).

2.2. Instrumentation

NO_2 was monitored using diffusive sampling tubes resulting in an integrated weekly average. The passive samplers were placed in a dedicated sampler shelter (IVL). Additionally, NO and NO_2 were measured at two school locations using an integrated measurement platform (Airpointer®, Recordum) that comprises a Chemiluminescence-based monitor. The monitor measured NO_2 on a higher temporal resolution of 1 min and averaged to 30-min, and was calibrated every two weeks using calibration gas (l'Air Liquide, 172.0 $\pm$ 8.6 ppb NO in N_2). In the official air quality monitoring stations of the Flemish Environment Agency, NO_2 is measured by means of Chemiluminescence (Monitor Thermo Scientific 42i) according to EU standard (EN, 14211, 2005). In the official monitoring station considered in this study, a beta-absorption technique (ESM FH 62I-R) is used to measure PM_{10}.

BC was measured using micro-aethalometers (AethLabs). The sampling was performed on a 5-min time resolution, equally averaged over 30-min, and finally integrated over the entire week. The micro-aethalometers were placed in a weatherproof housing which also included a battery, resulting in an autonomy of over 4 days. The battery change twice a week was done at the time of the filter replacement of the micro-aethalometers necessary to prevent filter saturation (Dons et al., 2013a).

Prior to the spring and autumn monitoring campaigns, micro-aethalometers were intercompared. Correction factors were established relative to a reference value being the average value of the instruments that were within 10% of the median value of all instruments. Based on these intercomparisons, BC measurements were adjusted by a correction factor of 0.73–1.09; only two instruments (out of 15) deviated more than 10%.