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Comparing land use regression and dispersion modelling to assess residential exposure to ambient air pollution for epidemiological studies

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ABSTRACT

Background: Land-use regression (LUR) and dispersion models (DM) are commonly used for estimating individual air pollution exposure in population studies. Few comparisons have however been made of the performance of these methods.

Objectives: Within the European Study of Cohorts for Air Pollution Effects (ESCAPE) we explored the differences between LUR and DM estimates for NO_2, PM_{10} and $PM_{2.5}$.

Methods: The ESCAPE study developed LUR models for outdoor air pollution levels based on a harmonised monitoring campaign. In thirteen ESCAPE study areas we further applied dispersion models. We compared LUR and DM estimates at the residential addresses of participants in 13 cohorts for NO_2; 7 for PM_{10} and 4 for $PM_{2.5}$. Additionally, we compared the DM estimates with measured concentrations at the 20–40 ESCAPE monitoring sites in each area.

Results: The median Pearson *R* (range) correlation coefficients between LUR and DM estimates for the annual average concentrations of NO_2, PM_{10} and $PM_{2.5}$ were 0.75 (0.19–0.89), 0.39 (0.23–0.66) and 0.29 (0.22–0.81) for 112,971 (13 study areas), 69,591 (7) and 28,519 (4) addresses respectively. The median Pearson *R* correlation coefficients (range) between DM estimates and ESCAPE measurements were of 0.74 (0.09–0.86) for NO_2; 0.58 (0.36–0.88) for PM_{10} and 0.58 (0.39–0.66) for $PM_{2.5}$.

Conclusions: LUR and dispersion model estimates correlated on average well for NO_2 but only moderately for PM_{10} and $PM_{2.5}$, with large variability across areas. DM predicted a moderate to large proportion of the measured variation for NO_2 but less for PM_{10} and $PM_{2.5}$.

1. Introduction

A large number of epidemiological studies have shown a clear association between long-term ambient air pollution exposure and adverse health effects (WHO, 2013). Several of these studies estimated individual air pollution exposures from stationary monitoring data, e.g. by using the nearest air pollution monitor to represent the pollution in entire cities (Dockery et al., 1993) to more complex approaches including spatial interpolation and kriging (Brauer et al., 2008; Künzli et al., 2005). Such methods provide estimates of large-scale spatial differences in air pollution concentrations, but are less effective in assessing intra-urban variation particularly when the number of monitoring sites is small. Recent studies have focused on intra-urban variation of air pollution, using indicators or proxies such as distance to the nearest road as well as pollutant levels estimated by land use regression (LUR), dispersion modelling (DM) including Chemical transport models (CTM) and hybrid models (HEI, 2010).

The LUR method, first developed by Briggs et al. (1997), uses least squares regression to combine monitored data with Geographic Information System (GIS)-based predictor data reflecting pollutant sources, to build a prediction model applicable to non-measured locations, e.g. residential addresses of cohort members. LUR modelling has been increasingly used in epidemiological studies because it is relatively cheap and can be easily implemented on the basis of purpose-designed monitoring campaigns or routinely measured concentrations and appropriate geographic predictors of air pollution sources (Hoek et al., 2008).

DMs are based on detailed knowledge of the physical, chemical, and fluid dynamical processes in the atmosphere. DMs use information on emissions, source characteristics, chemical and physical properties of the pollutants, topography, and meteorology to model the transport and transformation of gaseous or particulate pollutants through the atmosphere to predict, e.g., ground level concentrations (Holmes and Morawska, 2006; Kukkonen et al., 2012). Gaussian based DMs were originally developed as air quality management tools but have also been used in environmental epidemiology to model long-term exposures (Bellander et al., 2001; Wu et al., 2011). Chemical Transport Models have also been used to model short- and long-term exposure periods (Hennig et al., 2014). Few studies to date have conducted comparisons between LUR and DMs for their performance in estimating exposures (Beelen et al., 2010; Cyrys et al., 2005; Dijkema et al., 2011; Gulliver et al., 2011; Marshall et al., 2008; Sellier et al., 2014). These studies included different models, spatial resolution, pollutants and study areas, factors likely to have contributed to inconsistent findings within individual studies. As both LUR and DM are applied in epidemiology, there is a need for more comparison studies of these methods, addressing their respective advantages and strengths depending on the specific air pollution and health-related questions which are sought to be answered.

We compare LUR and DM to assess spatial variation of annual average ambient air pollution estimates at residential addresses within the framework of the European Study of Cohorts for Air Pollution Effects (ESCAPE), not taking into account population activity patterns or indoor air pollution. The ESCAPE study developed LUR models to estimate exposure at the residential addresses of cohort participants based on uniform monitoring campaigns and uniform modelling approaches in 36 study areas (Beelen et al., 2013; Cyrys et al., 2012; de Hoogh et al., 2013; Eeftens et al., 2012a,b). To several of these study areas we apply DM or use existing DM output, allowing for an in depth comparison to better understand the differences and/or agreements between LUR and DM estimates for use in epidemiological studies with long-term exposures. We include a range of exposure environments and populations across Europe, and focus, in particular, on the differences in estimated exposure at the individual participant level which is most relevant for interpretation of epidemiological studies.

2. Materials and methods

We estimated annual average outdoor air pollution concentrations for NO_2 in 13, PM_{10} in 7 and $PM_{2.5}$ in 4 of the 36 European cities/areas included in the ESCAPE study using both LUR and DM (Umeå region, Sweden; Stockholm County, Sweden (PM_{10}); Helsinki—Vantaa region, Finland ($PM_{2.5}$); Bradford, UK; London, UK (PM_{10}); Netherlands (PM_{10} & $PM_{2.5}$); Ruhr Area (PM_{10} & $PM_{2.5}$), Germany; Basel, Switzerland; Geneva, Switzerland; Lugano, Switzerland (PM_{10}); Rome, Italy ($PM_{2.5}$); Barcelona, Spain (PM_{10}); Athens, Greece (PM_{10})). The selection of study areas was based on the availability of existing dispersion models. A general discussion of these two modelling approaches is reported elsewhere (Hoek et al., 2008; Özkaynak et al., 2013).

We conducted several comparisons, depending on the comparability of the model outputs. The main comparison between the methods was made at the residential address of cohorts participants (referred to as LUR-DM). We also compared the DM estimates with measured concentrations at the ESCAPE monitoring sites. This was an independent validation, as monitoring data from the ESCAPE sites were not used as input data in the DM models. Recent studies have documented that the model R^2 and the leave-one out cross-validation R^2 overestimate the predictive ability of LUR models at independent sites (Basagaña