Atmospheric Environment 91 (2014) 15–23

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

# Spatio-temporal modelling of residential exposure to particulate matter and gaseous pollutants for the Heinz Nixdorf Recall Cohort

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## HIGHLIGHTS

- We model the spatio-temporal distribution of air pollution.
- The modelled exposure is assigned to residential addresses of study participants.
- The model leads to an improved and highly flexible exposure assessment.
- The model is suitable to the analysis of effects of long-term exposure.
- The model is suitable to the analysis of effects of short-term exposure.

## ARTICLE INFO

*Article history:*
Received 19 September 2013
Received in revised form
21 March 2014
Accepted 25 March 2014
Available online 26 March 2014

*Keywords:*
Heinz Nixdorf Recall Study
EURAD model
Spatio-temporal exposure modelling
Long-term exposure
Short-term exposure

## ABSTRACT

For the simultaneous analysis of short- and long-term effects of air pollution in the Heinz Nixdorf Recall Cohort a sophisticated exposure modelling was performed. The dispersion and chemistry transport model EURAD (European Air Pollution Dispersion) was used for the estimation of hourly concentrations of a number of pollutants for a horizontal grid with a cell size of 1 $km^2$ covering the whole study area (three large adjacent cities in a highly urbanized region in Western Germany) for the years 2000–2003 and 2006–2008. For each 1 $km^2$ cell we estimated the mean concentration by calculating daily means from the hourly concentrations modelled by the EURAD process. The modelled concentrations showed an overall tendency to decrease from 2001 to 2008 whereas the trend in the single grid cells and study period was inhomogeneous. Participant-related exposure slightly increased from 2001 to 2003 followed by a decrease from 2006 to 2008. The exposure modelling enables a very flexible exposure assessment compared to conventional modelling approaches which either use central monitoring or temporally static spatial contrasts. The modelling allows the calculation of an average exposure concentration for any place and time within the study region and study period with a high spatial and temporal resolution. This is important for the assessment of short-, medium and long-term effects of air pollution on human health in epidemiological studies.



*Abbreviations:* ANOVA, analysis of variance; CO, carbon monoxide [$mg/m^3$]; DMPS, differential mobility particle sizer; EURAD, European Air Pollution Dispersion; GIS, geographic information system; MSE, mean square error; $NH_3$, ammonium hydroxide [$\mu g/m^3$]; $NO_x$, nitrogen oxides [$\mu g/m^3$]; $NO_2$, en dioxide [$\mu g/m^3$]; NO, nitrogen monoxide [$\mu g/m^3$]; $O_3$, ozone [$\mu g/m^3$]; PM, particulate matter; PM1.0, mass concentration of particles less than 1.0 μm in size [$\mu g/m^3$]; PM2.5, mass concentration of particles less than 2.5 μm in size [$\mu g/m^3$]; PM10, mass concentration of particles less than 10 μm in size [$\mu g/m^3$]; Recall, Risk Factors, Evaluation of Coronary Calcium and Lifestyle; $SO_2$, sulphur dioxide [$\mu g/m^3$]; TPN, total particle number [*104/ml]; TDMPS, twin differential mobility particle sizer.

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http://dx.doi.org/10.1016/j.atmosenv.2014.03.052
1352-2310/

## 1. Introduction

For the simultaneous analysis of short-, medium and long-term effects of air pollution both spatially and temporally resolved exposure estimates are needed (Briggs, 2005). In the last years geographical information systems (GIS) have become powerful tools for exposure assessment in environmental epidemiology, especially for assessing air pollutants (particulate matter as well as gaseous pollutants) and for assigning spatially distributed exposures to individual humans.

Usually only a few monitoring sites are available in a study area so there is a need for models to estimate exposure at locations where exposure measurements are not feasible (Briggs, 2007; Jerret et al., 2005). Different approaches of exposure modelling were developed (Briggs, 2005). The simplest class of methods is based on the assumption that if objects are related then near objects are more strongly related than distant ones (Tobler, 1970), i.e. exposure is expected to decrease with increasing distance from emission source and there may be a cut-off distance after which the exposure caused by the emission source cannot be distinguished from the ambient (background) exposure. This assumption might not hold true if the effects of different emission sources may interfere, e.g. in urban environments. Nevertheless, these simple location-based methods are widely used. Common approaches are the use of distance to major roads defined by traffic density or street class (Gehring et al., 2006; Hoffmann et al., 2006) as a proxy for exposure and the buffering around local emission sources with a fixed buffer size (Maanty, 2007; Meng et al., 2007) categorizing people living within a buffer area as exposed.

Another class of methods makes use of (geo-) statistical interpolation techniques that use the data of monitoring or dedicated measurement sites to estimate air pollution concentrations at locations where exposure measurements are not available (Myers, 1994). Ordinary and universal kriging (Oliver and Webster, 1990; Jerret et al., 2001; Kim et al., 2009), inverse distance weighting (Moore et al., 2007; Su, 2007) and land use regression models (Aguilera et al., 2009; Briggs et al., 1997; Beelen et al., 2008; Larson et al., 2009; Slama et al., 2007; Su et al., 2008) are commonly used techniques. They offer the possibility to use additional (local) data (e.g. data on land use or topography) for a more realistic exposure modelling. Some problems may occur when using these techniques: For example, the distribution of monitoring sites is often biased toward specific types of area (e.g. sites with high traffic load are overrepresented) or exposure data on air pollution hotspots is not available (Briggs, 2005). These problems might weaken the quality of the exposure model.

All the afore-mentioned models follow a static approach, i.e. they usually do not take into account the spatio-temporal variability of air pollution. In reality, however, the spatial distribution of air pollution concentration levels in a specific area might not be constant over time and changes in the atmospheric conditions and land use, as well as transport conditions over short and large distances influence the distribution and concentration of air pollutants. To overcome these difficulties, sophisticated dynamic modelling techniques were developed. The best known method is dispersion modelling (Bellander et al., 2001; Cyrys et al., 2005; Memmesheimer et al., 2004). Other approaches were developed for single projects but not widely used (e.g. generalized additive mixed models (Yanosky et al., 2008), artificial neural networks (Thomas and Jacko, 2007)).

Up to now, most analyses of the effects of air pollution on health outcomes take into account either spatial or temporal variation of exposure. One of earliest attempts to use a combined spatio-temporal model is reported by Diez Roux et al. (2008) with a spatial resolution of a few kilometres incorporating the temporal dimension by a monthly residential history only. A different approach was applied by Gryparis and colleagues (von Klot et al., 2009) using a land use regression model with spatiotemporal parameterisation for the estimation of weekly exposure to traffic-related air pollution at the individual address of each study participant.

The decision as to which of the available modelling techniques is best suited for exposure estimation in a particular study depends on the aims of the study and the characteristics of the area (Briggs, 2005). We wanted to investigate the temporal pattern of changes in different physiologic outcomes (i.e. inflammation, blood pressure) in response to different air pollutants and the possible role of these outcomes as intermediates in coronary atherosclerosis using a prospective population-based cohort spanning three large adjacent cities in a highly urbanized region in Germany. Due to the large number and the heterogeneity of pollutant sources in urban environments, we expected that particle concentrations and size distributions would be subject to significant spatial and temporal variability throughout the study period of 8 years. In addition, we had to take into account that the usage of only few monitoring sites per city may not adequately represent the intra-city heterogeneity of exposure. Incorrect assumptions about heterogeneity may add to exposure misclassification which might increase the possibility of errors in risk estimates (Wilson et al., 2005). Furthermore we had to consider that for the assessment of short-term and long-term health effects small-area contrasts in air pollution emissions and concentrations are important. With the EURAD model, a sophisticated dispersion and chemistry transport model which had been developed for the simulation of air quality in Europe was available. EURAD allows for the exposure estimation on a small scale taking into account local and regional emissions from different sources, the topography of the area, and daily meteorology. This article describes the method of exposure assessment suited for the epidemiological analysis of short- and long-term effects of air pollution on health-related outcomes in a population-based study based on the EURAD model.

## 2. Material and methods

### 2.1. Study design

The Heinz Nixdorf Recall (**R**isk Factors, **E**valuation of **C**oronary **Cal**cium and **L**ifestyle) Study, which started in 2000, is an ongoing, population-based, prospective cohort study. The study rationale and design, which was approved by the relevant institutional ethics committees, have been described in detail elsewhere (Schmermund et al., 2002). The study population comprises 4814 randomly selected male and female participants aged 45–75 years from three large adjacent cities (Mülheim, Essen and Bochum) in the highly urbanized Ruhr area in Germany. Baseline examination (2000–2003) included a self-administered questionnaire, personal face-to-face interviews for individual risk-factor assessment, blood pressure measurements, anthropometric measurements and comprehensive clinical and laboratory tests (e.g. electrocardiograms (ECGs), electron beam computed tomogram (EBCT)). A follow-up examination to re-assess health status and individual risk factors was performed 5 years after baseline (2006–2008).

### 2.2. Exposure modelling

The dispersion and chemistry transport model EURAD (**Eur**opean **A**ir Pollution **D**ispersion, Memmesheimer et al., 2004) was used for the estimation of mass concentrations of particulate and gaseous pollutants and particle numbers concentrations.