

# Modelling of the exposure of population to urban air pollution

A contribution to subproject SATURN

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## Summary

A model is presented for the human exposure to ambient air pollution in an urban area. The main objective was to evaluate the exposure of population with a reasonable accuracy, instead of the personal exposures of specific individuals. We have utilised a previously developed modelling system for predicting the traffic flows, emissions originated from stationary and vehicular sources, and atmospheric dispersion of pollution in an urban area. A model was developed for combining the predicted concentrations, the location of the population and the time spent at home, at workplace and at other places of activity. Time-microenvironment activity data from working-age population was obtained from the *EXPOLIS*-study. The computed results were processed and visualised using the Geographical Information System (GIS) MapInfo. The utilisation of the modelling system has been illustrated by showing selected numerical results of nitrogen dioxide in the Helsinki Metropolitan Area in March 1996. The model developed has been designed to be utilised by the municipal authorities in urban planning, e.g., for evaluating impacts of future traffic planning and land use scenarios.

## Introduction

Models for evaluating exposure to air pollutants can be classified as statistical, mathematical and mathematical-stochastic models (modified from Ryan, 1992). The statistical approach involves the statistical determination of the measured exposures in terms of the factors that are assumed to influence these exposures. The mathematical modelling involves application of emission inventories, combined with atmospheric dispersion and population activity modelling. The so-called stochastic approach attempts to include a treatment of the inherent uncertainties of the model (e.g., caused by the turbulent nature of atmospheric flow). Most recently, mathematical exposure models have been presented by Bohler and Riise (1997), Jensen (1999) and Johansson et al. (1999).

## Objectives

We have developed a modelling system for predicting the traffic flows, emissions from stationary and vehicular sources, and atmospheric dispersion of pollution in an urban area (Karppinen et al., 2000a,b). The main purpose of this paper is to present the part of the mathematical modelling system, which is used to evaluate the exposure of human population to ambient air pollution. In principle, the model is applicable for any pollutant, if the required spatial concentration distributions are available.

## Activities

We have updated the previously-conducted emission inventory of NO<sub>x</sub> in the Helsinki Metropolitan Area for the years 1996 and 1997. The computations included approximately 5000 line sources, 169 point sources, area sources and the regional background concentrations.

We used the meteorological database of the Finnish Meteorological Institute, which contains weather and sounding observations. The mixing height of the atmospheric boundary

layer was evaluated using a meteorological pre-processor, based on the sounding observations made at Jokioinen (90 km northwest of Helsinki) and on routine meteorological observations.

We have utilized a modelling system developed for evaluating the traffic flows, emissions from stationary and vehicular sources, and atmospheric dispersion of pollution in an urban area. The modelling system has been described in more detail by Karppinen et al. (2000b).

The part of the modelling system that evaluates the exposure of population to air pollution has been named EXPAND (“EXPosure to Air pollution, especially Nitrogen dioxide and particulate matter”). A schematic diagram of the EXPAND model has been presented in Figure 1.

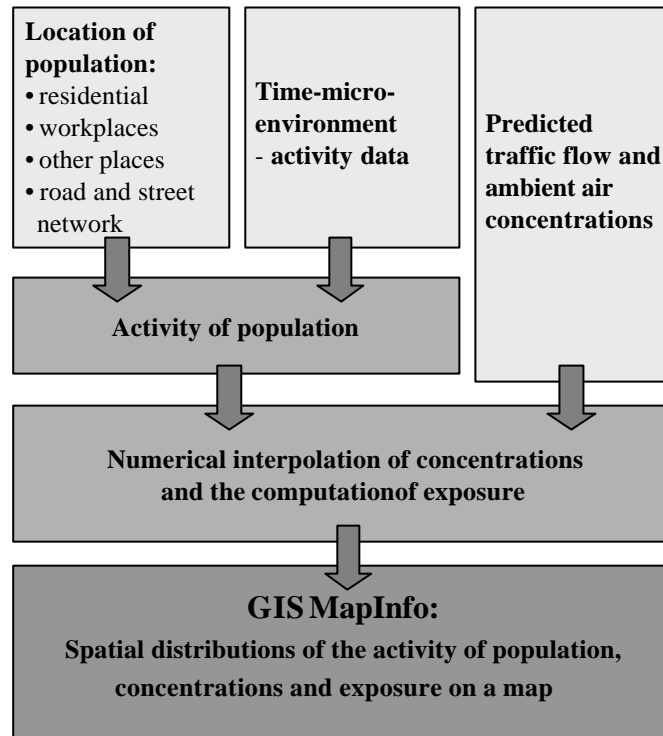


Figure 1. A schematic presentation of the exposure model.

The model utilises as input values (i) data on the spatial location of the population as a function of time, (ii) time-microenvironment activity data and (iii) computed spatial pollutant concentration distributions. The essential computational models of the system are a separate computer program for combining and processing the data and the GIS MapInfo. The modelling system yields as output the spatial distribution of the pollutant concentration, the activity of population and the exposure of population to ambient air pollution in the selected numerical grid.

The information on the location of population contains the residential and workplace coordinates, and the location of the road and street network.

We have utilised the time-activity data produced within the EXPOLIS study (e.g., Jantunen et al., 1999). EXPOLIS is a multicenter exposure study in Europe; the centres include Athens, Basel, Grenoble, Helsinki and Prague. The EXPOLIS study focused on the European adult urban populations, from 25 to 55 years of age, and their personal air pollution exposures to nitrogen dioxide (NO<sub>2</sub>), carbon monoxide (CO), fine particles (PM<sub>2.5</sub>) and 30 volatile organic compounds (VOC:s). Time-activity of the population was divided to four categories: home, workplace, traffic and other activities (free-time and recreational activities).

We have computed the concentrations of nitrogen oxides ( $\text{NO}_x$ ) and nitrogen dioxide ( $\text{NO}_2$ ) in the Helsinki Metropolitan Area for 1996 and 1997. The hourly concentration time series were computed on a receptor grid, which contains approximately 10000 receptor points.

We utilised the above mentioned data sets in evaluating the activity of population. We combined the home coordinates, the number of inhabitants at each home location and the time spent at home. Correspondingly, we combined the workplace coordinates, the number of employees and the time spent at workplace. The activity of the population in vehicular traffic was evaluated based on the computed traffic flow information and the time-activity data.

## Results

The concentrations of  $\text{NO}_2$  and  $\text{NO}_x$  were computed for years of 1996 and 1997. A statistical analysis was performed on the agreement of the predicted and observed hourly time series of concentrations at four permanent monitoring stations and three mobile stations of YTV in 1996 and 1997 (Kousa et al., 2001). The so called index of agreement between predicted and measured time series of the  $\text{NO}_2$  concentrations varied between 0.65 and 0.82, while the fractional bias values ranged from  $-0.29$  to  $+0.26$ .

In this study, we have categorised population exposure to  $\text{NO}_2$  into five time periods; these are called for simplicity morning (6 a.m. – 9 a.m.), day (9 a.m. – 3 p.m.), afternoon (3 p.m. – 6 p.m.), evening (6 p.m. – 10 p.m.) and night (10 p.m. – 6 a.m.). We have compiled the *EXPOLIS* time-activity data corresponding to these diurnal periods. The ‘morning’ and ‘afternoon’ periods correspond to the most busy commuting periods, while the other three periods have been selected to represent times, in which people are mostly at one place, either at home (‘evening’ and ‘night’ periods) or at workplace (‘day’ period).

We computed monthly average concentrations and average concentrations during the five above mentioned diurnal time periods in each month for  $\text{NO}_2$ . Modelled concentrations were interpolated for the whole Helsinki Metropolitan Area. Interpolated concentrations and activity of population were combined, and the exposure of population to ambient concentrations was evaluated. Exposure was computed numerically in a grid with a spatial resolution of 100 m.

Example results on the exposure of population to ambient  $\text{NO}_2$  concentrations have been presented in Figure 2. These results are shown for the evening period (from 6 p.m. to 10 p.m.), as a monthly average value in March 1996. The activity values were computed by multiplying the number of population by the time spent in each grid cell and divided by the hours of the period (this way it is possible to compare different time periods of the day with each other). The exposure values were computed by multiplying the monthly mean concentration by the number of population and the time spent in each grid cell.

## Conclusions

This paper presents a mathematical exposure model, which combines predicted concentrations, the location of the population, and the time spent at home, in the workplace, in traffic and at other places of activity. The main objective was to evaluate the spatial and temporal variation of exposure of the whole urban population to ambient air pollution in different microenvironments. The model includes a treatment of all of the most important categories of population activity, including also the exposure in vehicular traffic.

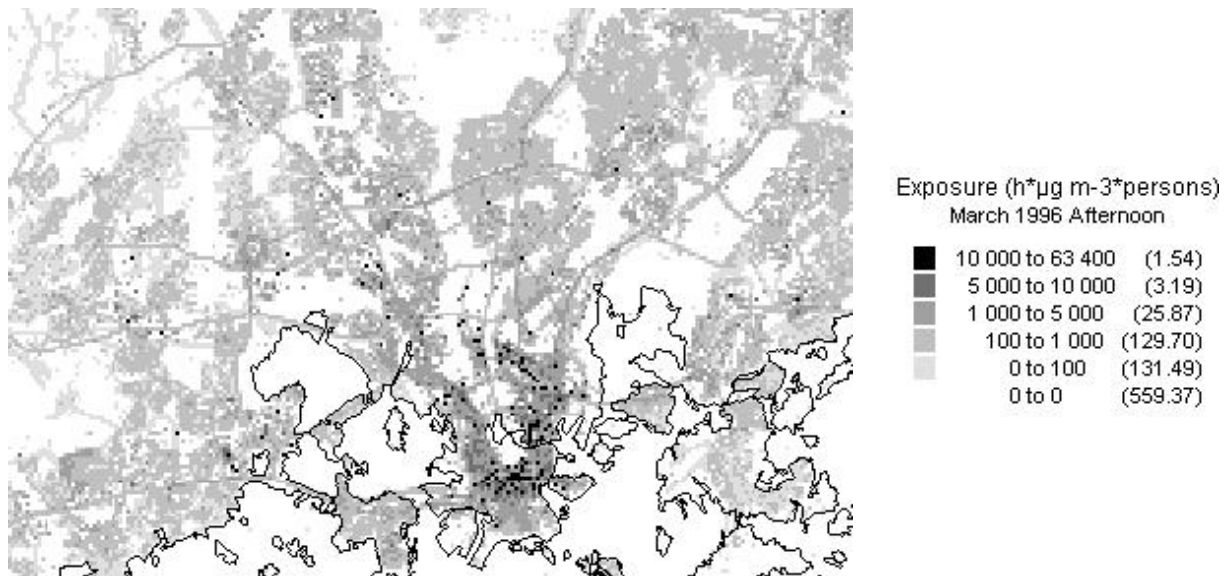


Figure 2. The predicted exposure of the population to NO<sub>2</sub> concentrations ( $\mu\text{g m}^{-3}$  persons), evaluated for the afternoon time period, as an average value in March 1996. The values in brackets in the legend refer to the number of square kilometres with the exposure in the selected range. The grid size is 100m \* 100 m, the size of the depicted area is 23 km x 16 km, and the solid black line is the coastline.

### Acknowledgement

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