The spatial and temporal variation of the exposure of population to ambient air pollution in Helsinki

Ari Karppinen[1], Anu Kousa[2], Jaakko Kukkonen[1], Päivi Aarnio[2] and Tarja Koskentalo[2]
[1] *Finnish Meteorological Institute (FMI), Air Quality Research, Sahaajankatu 20 E, FIN – 00810, Helsinki, Finland, Fax +358 9 1929 5403 - email: Ari.Karppinen@fmi.fi*
[2] *Helsinki Metropolitan Area Council (YTV), Opastinsilta 6 A, FIN-00520, Helsinki, Finland*

Keywords: exposure, nitrogen dioxide, air pollution, dispersion model, air quality assessment.

1 Introduction

In numerous studies, population exposure to air pollution has been estimated based on data from ambient air monitoring sites at specific locations. However, the measurement data from these stations does not necessarily represent areas beyond their immediate vicinity, for pollutants with a substantial spatial variation in urban areas. In any case, a substantial amount of work resources and an extensive set of monitoring equipment are required in order to carry out the measurements to obtain, e.g., residential outdoor concentrations and personal exposures.

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. Source apportionment methods can be used in order to analyse the contribution of various emission sources to the total human exposure.

Most recently, several mathematical exposure models have been presented. The air quality assessment system AirQUIS has been extended to include a fairly simple exposure model (Bohler and Riise, 1997). The exposure modelling part of the system associates a population number with each individual building, and combines this information with the computed ambient air concentrations, utilising a GIS system.

The model presented by Jensen (1999) is based on the utilisation of traffic flow computations and the Operational Street Pollution Model (OSPM) for evaluating the outdoor concentrations. The model was applied to evaluate population exposure in one specific municipality in Denmark. Limitations of this study included that only pollution originated from local traffic sources were directly considered, and the complexity of the model computations did not allow the evaluation of a spatially more extensive area.

Johansson et al., 1999 evaluated population exposure to NO_2 and particulate matter (PM) within the SHAPE study (Stockholm Study on Health Effects of Air Pollution and their Economic Consequences). They used a multiple-source emission and Gaussian dispersion modelling system to predict the spatial distributions of the NO_2 and PM_{10} concentrations in the county of Stockholm. The population locations were obtained from official national statistical data sets that classify separately the night and day time locations. A limitation of the modelling system was that a treatment for the chemical reactions of nitrogen oxides is not included. The model applied was not combined to a GIS system.

We have utilised emission inventories previously collected for the Helsinki metropolitan area, and the atmospheric dispersion modelling system containing the UDM-FMI and CAR-FMI models (Karppinen et al., 2000a,b). In order to evaluate the population exposure, a model was developed for estimating the time spent by the population at home, at workplace, in traffic and at other places of activity.

2 Methodology

2.1 Emissions and meteorological data

We have updated the previously-conducted emission inventory of NO_X in the Helsinki Metropolitan Area (Karppinen et al., 2000a) for the years 1996 and 1997. The inventory includes the emissions from various mobile sources (road traffic, harbours and marine traffic, and aviation) and stationary sources (power plants, other point sources and residential heating).

We used the meteorological database of the Finnish Meteorological Institute, which contains weather and sounding observations. A combination of data from the stations at Helsinki-Vantaa airport (about 15 km north of Helsinki town centre) and Helsinki-Isosaari (an island about 20 km south of Helsinki) were employed. 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.

2.2 Atmospheric dispersion modelling

The dispersion modelling is based on a combined application of the road network dispersion model CAR-FMI (Härkönen et al., 1995), applied for evaluating the dispersion of pollution originating from vehicular traffic, and the Urban Dispersion Modelling system UDM-FMI (Karppinen et al., 1998), for evaluating the dispersion from stationary sources. The system includes a meteorological pre-processing model and a statistical and graphical analysis of the computed time series of concentrations. We computed the concentrations of nitrogen oxides (NO_X) and nitrogen dioxide (NO_2) in the Helsinki Metropolitan Area for 1996 and 1997.

2.3 Exposure modelling

The main objective was to evaluate the exposure of population with a reasonable accuracy, instead of the personal exposures of specific individuals. We also evaluate directly only the exposure to ambient air pollution, i.e., the pollutant concentrations in indoor and outdoor air were assumed to be equal.

The information on the location of population contains the residential and workplace coordinates, and the location of the road and street network. The dataset provides geographic information on the total number of people living in a particular building or working at a particular workplace. The location of the population in vehicular traffic was evaluated based on the computed traffic flow information, which is available separately for buses and private cars for each street section on an hourly basis.

We utilised the time-activity data produced within the EXPOLIS study (Jantunen et al., 1999). 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_2), carbon monoxide (CO), fine particles ($PM_{2.5}$) 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 utilised the above mentioned data sets in evaluating the activity of population combining 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.

3 Results and Discussion

We have categorised population exposure to 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.). 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 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 activity of population, the ambient air concentrations of NO_2 and the exposure of population to ambient NO_2 concentrations have been presented in Figure 2. These results are shown for the morning period (from 6 a.m. to 9 a.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. The exposure values were computed by multiplying the monthly mean concentration by the number of population and the time spent in each grid cell.

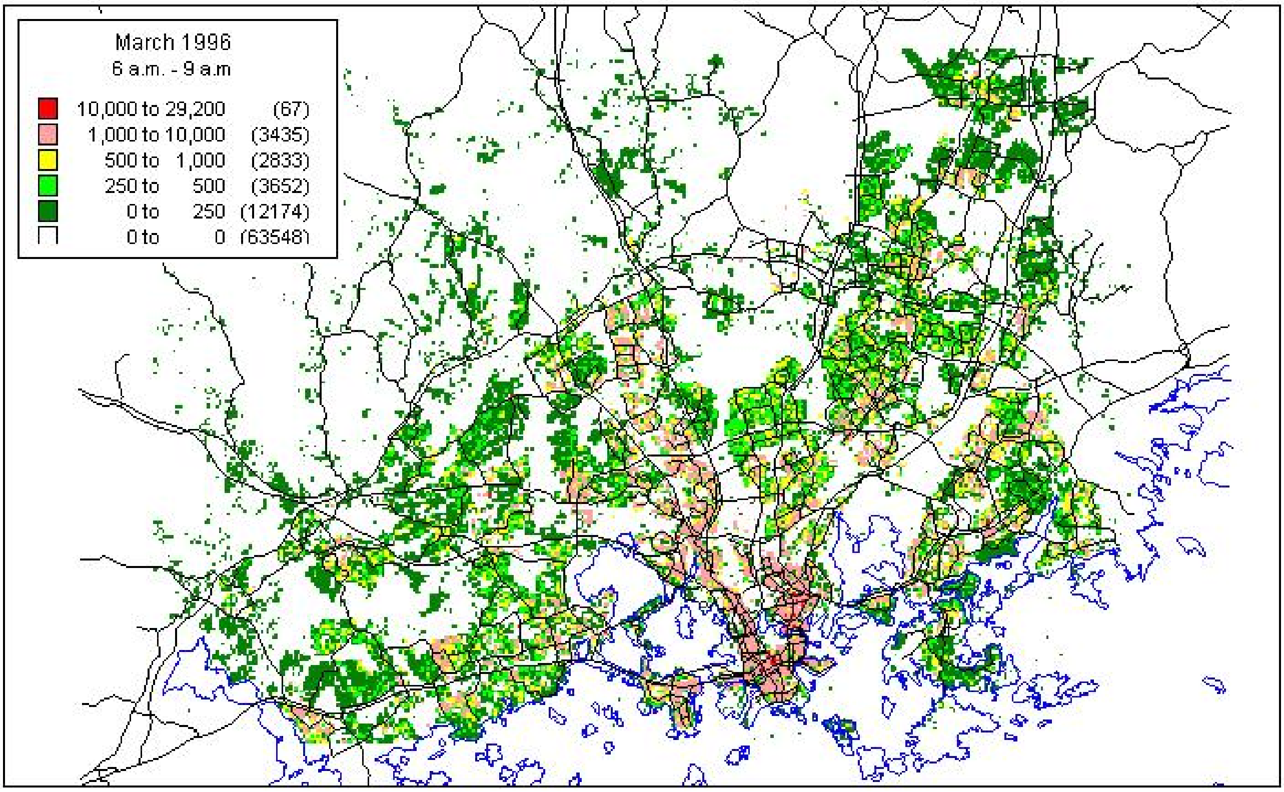

Figure 1 Modelled potential exposure ($\mu g/m^3$*h) to NO_2 in the Helsinki Metropolitan Area during the morning hours (from 6 a.m. to 9 a.m.) in March 1996. The exposure values were computed by multiplying the monthly mean concentration by the number of population and the time spent in each grid cell.

The distribution of population vs. modelled NO_2 concentrations for three time periods (morning, day, afternoon) are presented in Figure 2. It can be clearly seen that people in traffic are exposed to the highest NO_2 concentrations while the time spent in traffic is very short in comparison to the time spent at home and work. It can be concluded that the NO_2 concentrations at home and at work are the most important factors for the total NO_2 exposures.

4 Conclusions

This paper presents an exposure model, which combines the predicted concentrations, the location of the population and the time spent at home, at workplace and at other places of activity. The computed results are processed and visualised using the Geographical Information System (GIS) MapInfo.

The main advantages of our exposure model compared with corresponding models are (i) our model includes measured time-microenvironment activity data from the random sample of working age

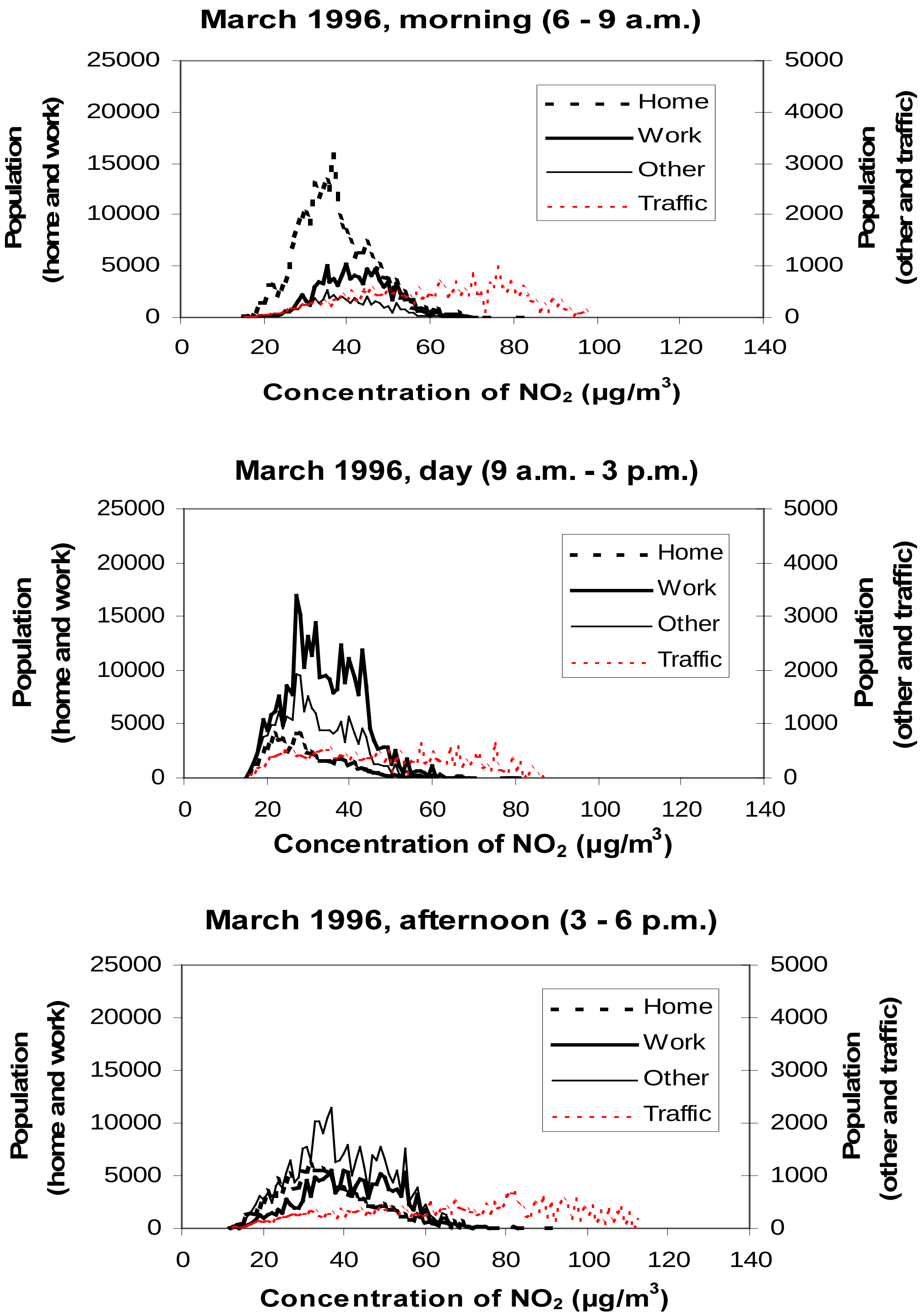

Figure 2 Distribution of population number vs. NO_2 concentrations in the Helsinki Metropolitan Area during daytime hours (from 6 a.m. to 6 p.m.) in March 1996.

citizens in the Helsinki Metropolitan Area, (ii) use of GIS enables to view spatial and temporal variations of the exposure of population and (iii) use of time periods and microenvironments enables to compare the exposure of population during different time periods and compare the exposure of population at home, at workplace, at other location and in traffic.

The model can be utilised by the municipal authorities in urban planning for evaluating and asessing the impacts of future traffic planning and land use scenarios. This assessment includes also evaluation of the exposure of population in different scenarios.