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Mapping human exposure to traffic air pollution using GIS

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Abstract

An ongoing PhD project has the objective to develop a model for population exposure to traffic air pollution in order to improve assessment of health impacts and in support of risk management. A selected urban area is used as a case study. Applying a Geographic Information System (GIS), the model combines calculated air pollution data using the Danish Operational Street Pollution Model (OSPM) and available population data from existing administrative databases. A simple population dynamics model will later on be established to model the number of people which simultaneously are present in a given area at a given time applying simple time-activity patterns. The microenvironments considered are: residences, working places, and streets. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

In developed countries, road transport has become the dominant source of air pollution especially in larger urban areas where traffic air pollution in busy streets may constitute 80 to 90% of the pollution levels. At Danish ambient levels, the traffic air pollutants identified as health hazards are: fine particles, NO_2, O_3, PAH, benzene, 1,3-butadiene, ethene and propene, and aldehydes (formaldehyde, acrolein, acetaldehyde). Fine particles are believed to be the most critical pollutant and main contributor

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to excess mortality especially among people suffering from respiratory and cardio-vascular diseases [1].

Use of ambient fixed monitor stations as indicator for population exposure is a very crude procedure. Personal exposure measurements give detailed information about exposure of individuals but are costly and only limited studies have been carried out. Various exposure models have been developed that combine microenvironment concentrations with individual time–activity patterns and extrapolation to the entire population to give population exposure distributions [2].

The present project takes a microenvironment approach to population exposure modelling but adds a geographic dimension by taking advantage of GIS, digital maps and administrative databases. The objectives of the research project are: (a) to develop an exposure model that combines modelled air pollution data using the Danish Operational Street Pollution Model (OSPM), population data using existing administrative databases, digital maps and a GIS. A simple population dynamics model will be established to model the number of people present in a given area during a given time using simple profiles for time spent in the various areas (at home, at work, and in transit). Additionally, ratios between indoor and outdoor concentrations will be taken into account. The model is tested in a case study for a selected urban area (b) to carry out air quality assessment and (c) to carry out examples of impact assessment of selected urban and traffic planning measures in support of risk management.

2. Methodology of exposure modelling

The method is an indirect exposure determination based on a microenvironment approach relying on presently available data and statistics. The method is illustrated in Fig. 1.

The Danish Municipality of Middelfart has been chosen as the case study area due to easy availability of most data and since a small municipality of about 19,000 inhabitants is sufficient for development and testing of the methodology although air pollution levels are relatively low.

The address point is used as an exposure indicator. Air pollution levels are calculated for each house number and all people living or working at the address are assigned the estimated air pollution. Modelled levels represent ground level concentrations since the receptor point will be located about 1 m in front of the facade and in the height of 2–3 m.

Concentration levels are determined using the Operational Street Pollution Model (OSPM) that calculates ambient hourly concentration levels based on inputs of the street configuration and hourly inputs of traffic, meteorological parameters and urban background concentrations [3]. Pollutants include: CO, NO_2, NO_x ($NO + NO_2$), O_3 and benzene. Traffic emissions are estimated based on emission factors together with average daily traffic (ADT), the percentage of heavy vehicles and the travel speed for each street section applying a default seasonal, weekly and diurnal variation in traffic loads to obtain hourly traffic inputs as well as default values for cold starts [4].

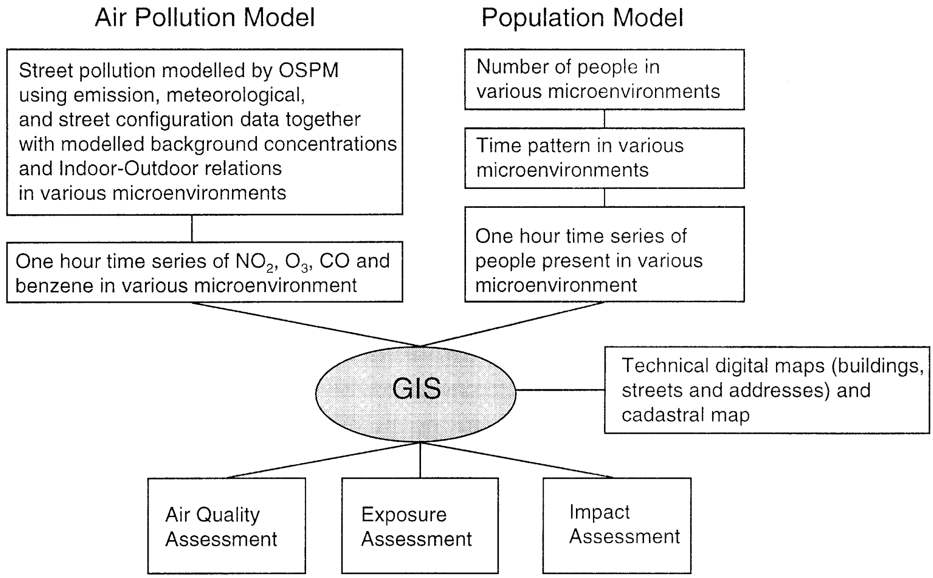

Fig. 1. Outline of the methodology for the exposure modelling in the present study.

Meteorological parameters are taken from a meteorological mast at a nearby larger city (Odense). Since the monitoring programmes only cover a few larger cities in Denmark it has been necessary to develop an extrapolation method to estimate the urban background concentrations in a small city like the case city. The reference for the method is the concentrations observed in Odense 40 km from the case city which has been scaled down applying a method that estimates background concentrations for area sources of known emission density based on the assumption that the concentrations are evenly distributed and that the dispersion depends linearly on the dispersion distance (city diameter) [4]. To determine the resulting pollution levels indoor from ambient levels empirical indoor/outdoor ratios for the various pollutants will be applied for buildings and means of transport (cars and buses).

The urban area will be divided into three general microenvironments: residences, working places, and streets.

Studies on time–activity patterns have not been carried out in Denmark from an exposure point of view. However, some statistical population data is available concerning the use of time [5,6]. Default diurnal variation of time spent in various microenvironments for different population groups will be established.

ArcView is used as the Geographic Information System (GIS) for development of the exposure model. GIS is a software that encompasses storage, retrieval, analysis and display of spatial-geographical data. GIS is a promising tool for exposure modelling due to the increase in coverage and quality of digital maps, developments in administrative databases managed by the authorities and developments of more user-friendly desktop GIS with increasing number of analytic features.

An urban landscape model has been developed using ArcView, the associated program Avenue, and digital maps to automatically generate the street configuration input parameters required by the street pollution model. The type of street configuration data generated from the digital map is shown in Fig. 2. Geocoding of the buildings is a requirement for development of the urban landscape model since the buildings have to be identified in the map in order to retrieve information in the Building and Residence Database about the height of the buildings [7].

The Danish authorities manage a number of comprehensive and detailed national databases for administrative purposes. These databases have two important features: all objects are uniquely identified and it is possible to combine the data from different databases due to common keys. An example is the address which also serves as the most important common key in this project.

The following databases are used to generate input for the exposure model: the Central Person Database (CPR), the Central Business Database (CER), the Building and Residence Database (BBR), the National Address Database, and a local traffic and road database.

The Central Person Database (CPR) managed by the Ministry of Residence Affairs

Fig. 2. Street configuration parameters generated by the urban landscape model for use in the OSPM to calculate air pollution levels. The digital map includes building polygons, address points and polylines to represent the middle of roads.

has information on each person in Denmark and the database is used to identify the gender, age and number of people living at their Residence address. Since each person is uniquely identified it is possible to estimate personal exposure for each individual for the residence microenvironment.

The Ministry of Economic Affairs manages the Central Business Database (CER) which contains information on all public and private companies. The database does not identify the individual employees but provides information about the total number of people working at a given working place identified by the address. Based on this information it is only possible to estimate population exposure for the total number of people working at various working places and it is not possible to link the exposure at the working place microenvironment to the residence microenvironment on a person to person basis.

The Building and Residence Database (BBR) managed by the Ministry of Housing contains detailed information on all buildings and residences. The database is used to estimate the height of buildings which is one of the parameters required about the street configuration to calculate air pollution.

Most municipalities manage a road and traffic database for primarily road maintenance purposes. All roads in a municipality have unique names and a unique identification code. Since most streets consist of several street sections each section is normally identified by a from–to kilometric distance. The Average Daily Traffic (ADT), the number of heavy vehicles and the travel speed are usually available from these databases and are the only input parameters needed for the model. Most municipalities including Middelfart have not established a link between their administrative traffic and road database and the digital technical map. Part of the project has therefore been to assign traffic data to the geocoded road network in the digital map. For the street environment it is only possible to estimate population exposure based on the total amount of time people spend in the streets since no information is available on how individuals travel on the network.

The Ministry of Housing has started to establish a new database containing the locations of addresses. This is the only administrative database that has a georeference, that is, the address can be geographically located according to x,y-coordinates.

Two kinds of digital maps are relevant for exposure modelling: technical and cadastral maps. Technical maps may contain many different objects since it is based on photogrammetry. The objects relevant for exposure modelling are streets, buildings and address locations which are represented as lines, polygons and points, respectively. However, a requirement for use of administrative databases is that there is a unique reference between the map and the database called a georeference or geocoding. For technical maps only addresses and streets are geocoded. An address is represented as an x,y-coordinate and located at the front door about 1–2 m inside the building polygon. The address has a unique identification consisting of a municipality code, a street code and a house number. Similarly, a street is represented as a series of x,y-coordinates and has a unique identification consisting of a municipality code and a street code. To a very large extent, the buildings can be automatically geocoded in GIS using cadastral maps and the Building and Residence Database. The cadastral map only serves as a tool for geocoding of the buildings.

3. Application and perspectives

The exposure model is an integrated flexible multi-purpose tool designed for the urban scale with a high geographic resolution primary suitable for planning purposes within population exposure assessment, air quality assessment and impact assessment.

Exploring the visualisation and analytic features of GIS the model gives a geographic dimension to input and output data. Data may be displayed as points (e.g. data related to addresses), polygons (e.g. data related to buildings or contour plots), lines (e.g. data related to streets), and grids (e.g. population density). An example of an application of the model concerning air quality mapping is given in Fig. 3 for a small selected area of the central part of the town of Middelfart which has about 10 000 inhabitants. The selected area has about 1150 inhabitants and 550 addresses.

The model gives population exposure estimates based on estimated hourly time series of ambient air pollution levels for three microenvironments separately: residences, working places and streets. For the residence environment differences in exposures between various population groups presented by gender and age can be estimated since

Fig. 3. Annual means of 1-h benzene concentrations ($\mu g/m^3$) in the down town area of a small city using the address point as indicator.

data on individuals is available but for the working place and street environment population exposure estimates cannot be related to individuals. It is also possible to use the model to estimate personal exposures to ambient traffic pollutants provided that detailed time–activity data is collected for the individuals in question.

Rough health risk assessment may be carried out based on the predicted exposures provided that dose–response relations are available. Comparisons of air quality guidelines with estimated air quality levels and population exposures may help assess the health risk. The model may also be used for geographical epidemiology linking exposure estimates to health endpoints in smaller geographic areas [8].

The model may serve decision-support purposes in support of risk management and risk reduction. Air quality and exposure mapping and hot spot identification may be carried out. Impact assessment of alternative urban and traffic control strategies and what-if scenarios can also be carried out provided that the consequences to the input parameters of the model are known (e.g., changes in traffic load and composition, emission, and street data).

Apart from research in issues of exposure assessment, health risk assessment, and risk management the exposure model may be further developed into an Urban Air Quality Information and Management System for use by local authorities for urban and traffic planning purposes.

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