The role of PM_{10} in air quality and exposure in urban areas

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Abstract

In recent years, there has been an increase of scientific studies confirming that long- and short-term exposure to particulate matter pollution leads to adverse health effects. The calculation of human exposure in urban areas is the main objective of the current work combining information on pollutant concentration in different microenvironments and personal time-activity patterns. Two examples of PM_{10} exposure quantification using population and individual approaches are presented. The results are showing important differences between outdoor and indoor concentrations and stressing the need to include indoor concentrations quantification in the exposure assessment.
Keywords: air pollution, respiratory diseases, exposure, particulate matter.

1 Introduction

Every day, a person breathing is exposed to different concentrations of atmospheric pollutants, as he moves from and to different outdoor and indoor places. Particulate matter, coarse and fine, is one of the pollutants of most concern in terms of adverse health effects [1]. Epidemiological studies point out tobacco smoke, indoor and outdoor pollutants as preventable risk factors of respiratory diseases such as cancer, allergic diseases, asthma and other chronic respiratory diseases [2]. Smoke from fuels, urban air pollution or occupational airborne particulates contribute to the increase of disability-adjusted life years (DALYs, one DALY represents the loss of one year of full health) either in

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developed and developing countries [3]. For both chronic and acute health effects, the elderly, children, and those suffering from respiratory or heart conditions seem to be most at risk.

Air pollution problems related to particulate matter are more frequent and severe at urban areas, with high population density, and where industrial and traffic particulate matter emissions are the major contributor to air pollution.

Health effects of air pollution are the result of a sequence of events, which include release of pollutants, their atmospheric transport, dispersion and transformation, and the contact and uptake of pollution before the health effects take place. The conditions for these events vary considerably and have to be accounted for, in order to ensure a proper assessment.

Studies of human exposure to air pollution have different applications, namely: i) impact assessment of population exposure, in connection with various types of management such as traffic and city planning; ii) comparison of the exposure of different specific population groups; iii) estimation of the average or peak exposures of the population in connection with, for example, health assessment; iv) identification of the most important sources of pollution exposure; v) identification of possible associations between exposure and health effects [4].

Exposure studies can be carried out to obtain estimates of the exposure of the individual (personal exposure) or for a larger population group (population exposure). The exposure can be obtained from direct measurements on individuals or can be determined from model calculations [4]. The former is used to access individual dose and the later for strategic studies, for example, to estimate the number of inhabitants exposed above limit value.

The general approach for exposure estimation can be expressed by:

$$Exp_i = \sum_{j=1}^{n} C_j t_{i,j} \qquad (1)$$

where Exp_i is the total exposure for person i over the specified period of time; C_j is the pollutant concentration in each microenvironment j and $t_{i,j}$ is the time spent by the person i in microenvironment j.

This paper explores two different approaches to analyse the impact of air pollution on human health, focused on the estimations of population exposure and individual exposure, applied in two different case studies.

2 Population exposure

The exposure of an entire population to PM_{10} air concentration is a useful parameter to evaluate air quality effects on human health. The assessment of measured ambient air particulate matter concentrations in Portugal has been carried out for the past few years to evaluate their effect on human exposure and health. Urban areas are particularly of concern due to usual high PM emissions and population density.

2.1 Study case

Porto is the second biggest city of Portugal, located on the coast. The municipalities in the region are characterized as urban (workplaces) and suburban (mainly industrial and residence areas) with different population density accordingly.

The analysis of the data from the air quality network of Porto, in the period 2001-2004, reveals that PM_{10} levels have exceeded the limit values (LV) established by legislation for the protection of human health for the daily average as well as for the annual mean.

Air quality modelling tools have been used to evaluate the air quality over the Metropolitan Area of Porto (MAP) showing also high levels of PM_{10} where air quality monitoring stations do not exist.

Therefore, the MAP was selected as a study case to estimate the population exposure to PM_{10} by the application of an exposure module linked to an air quality modelling system.

2.2 Methodology

To model human exposure, over a selected region, by a deterministic approach, three types of input data are needed: the population characterization (number of people and daily time-activity pattern), the spatial distribution of the microenvironments visited by the population and the temporal variation of PM_{10} concentrations in each microenvironment.

The Portuguese National Statistics Institute (INE), in 1999, 2000 and 2003, did some inquiries to the resident population (students over 15 and employees) of the MAP focusing on: mobility of the population, work/school-home displacements, displacements from and to the MAP presented as Origin-Destination matrixes (number of people and time spent in displacement by mean of transport). Those matrixes allowed calculating the number of people that enters and leaves each municipality of MAP and thus, the people presented during the day and during the night in each cell of the modelling domain. The time spent was also addressed in the INE national enquires which has permitted the definition of a daily time-activity pattern per microenvironment considered in the exposure module, on an hourly basis, for the students and employed population of Portugal. According to the detail of information gathered it was possible to consider four different microenvironments – outdoor, home, other indoors and in vehicle.

The exposure module calculates the indoor concentrations using the outdoor concentrations simulated by the application of MM5-CAMx modelling system for the year 2004 and for a domain of 3 km horizontal resolution covering the MAP [5] and indoor/outdoor relations obtained experimentally (Table 1) [6,7].

Figure 1 presents the input data prepared for the exposure modelling application based on all the compiled and treated information, namely the population presented in the study domain during the day and night, the time-activity pattern for outdoor, home and other indoor microenvironments, the daily

Table 1: Indoor-outdoor relations considered in the exposure module for PM_{10}.

Home	Other indoors	In vehicle
$C_{it}(\text{day}) = 48 + 0{,}51C_{out}$ $C_{in}(\text{night}) = 20 + 0{,}52C_{out}$	$C_{in}(\text{day}) = 48 \cdot (1 - 0.14) + 0{,}51C_{out}$ $C_{int}(\text{night}) = 20 \cdot (1 - 0.14) + 0{,}52C_{out}$	$C_{vehicle} = 13{,}1 + 0{,}83C_{out}$

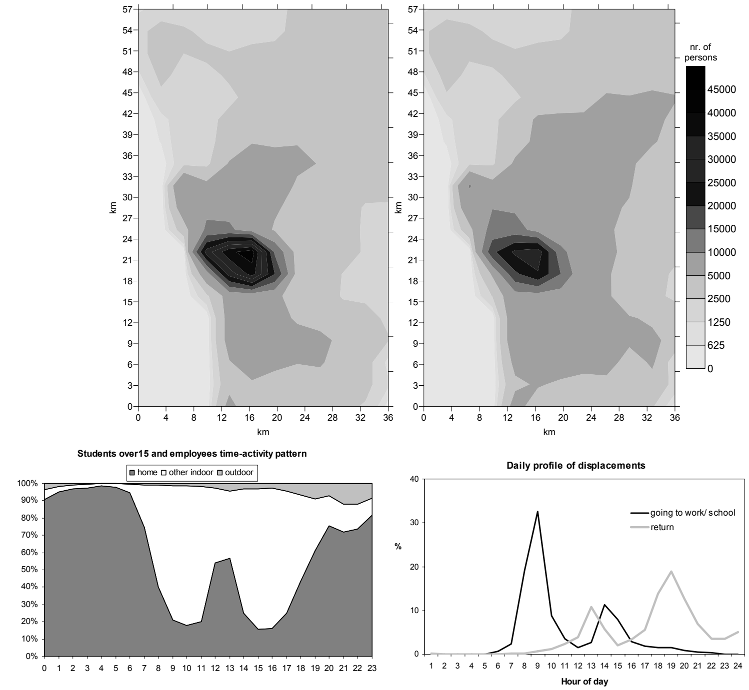

Figure 1: Input data for exposure module to estimate population exposure in the Metropolitan Area of Porto.

profiles of displacements to and from work/school and the PM_{10} annual average concentration field simulated by the MM5-CAMx modelling system [8,9].

2.3 Results

The application of the air quality-exposure modelling system has permitted the estimation of the spatial distribution of the exposure to PM_{10} for the population subgroup selected and for weekdays (no information for the weekend time-activity pattern was available). Figure 2 presents the annual averages of simulated PM_{10} concentration and individual exposure fields for the study domain.

The PM_{10} concentration field shows high levels of PM_{10} in Porto urban area, tending to decrease with the increase of radius distance to the city. The spatial distribution of exposure levels follows the concentration field, however with lower levels.

Considering the annual limit value for PM_{10} of 40 $\mu g.m^{-3}$, concentration results reveal a non-accomplishment of the legislation in terms of air quality possibly leading to significant impacts that are minimized regarding human health as exposure results show.

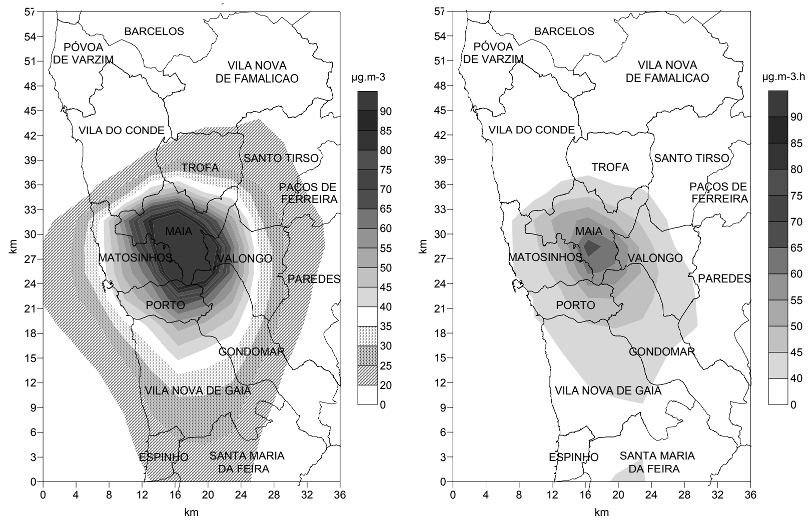

Figure 2: Annual average fields of simulated PM_{10} concentration and individual exposure for the Metropolitan Area of Porto study domain.

To evaluate the behaviour and applicability of the exposure module applied to MAP it would be important to validate the obtained results. However, previous similar studies have not been performed for Portugal and there are no exposure measurements to compare the modelling results with.

3 Individual exposure

Individual exposure is quantified for single individuals as they represent some population subgroups. Different methodologies could be applied for this purpose using: (i) direct measurements, or; (ii) estimations based on exposure concentration data and the time of contact.

3.1 Study case

One of the Portuguese middle-size towns currently not presenting significant air pollution problems was selected in this study. The town of Viseu is located in the central Portuguese mainland region, near important road transport networks and a high urban development is expected in a near future.

Asthmatic children were identified as the population subgroup more susceptible to air pollution and therefore they are the focus of the exposure estimation. The work was developed as a part of SaudAr (The Health and the Air we breath) project, which main objective is to contribute for the urban sustainable development by preventing air pollution problems and health related diseases in the future due to expected economical development.

In total, 4 schools were selected, including 2 located in town centre – *Massorim* and *Marzovelos* – and 2 in city suburbs – *Ranhados* and *Jugueiros* (Figure 3). The ISAAC (International Study of Asthma and Allergies in Childhood) questionnaire was applied to 805 children between ages 6 and 12 to identify those presenting respiratory disease.

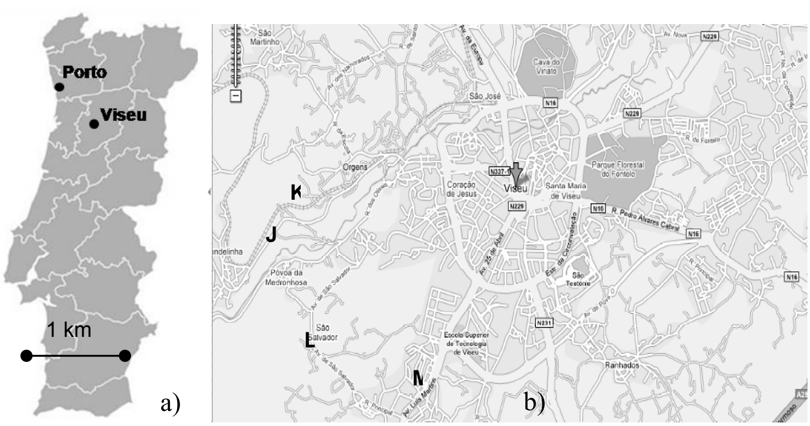

Figure 3: Geographic location of Viseu in Portugal (a) and location of the schools in Viseu (b).

3.2 Methodology

Similarly to the population exposure, the individual exposure was estimated using the microenvironment approach and calculated according to Equation 1. The input data required for the exposure quantification are determined separately for each individual under the study. For this purpose two main tasks were carried out: a) the definition of the daily activity profile of each child for a typical winter and summer school week, which allowed the identification of the microenvironments frequented by those children and the time spent in each one; and b) the air quality characterisation of those microenvironments. The daily activity profile was established through personal interviews of parents and child during the medical consulting hour. The air quality evaluation in the identified microenvironments, both outdoor and indoor, was performed using a multi-strategy approach: measurements during field campaigns and air quality modelling simulations.

Campaigns and model simulations were performed both in winter (14–28 January 2006) and summer time (19-26 June 2006) to take into account seasonal variability of pollutant levels. In microenvironments where outside measurements where not possible, PM_{10} concentrations where obtained through air quality modelling. These microenvironments were geo-referenced and outdoor concentrations where obtained directly from modelling while for indoor concentrations the relations presented in Table 1 were used. With these data daily personal exposure to PM_{10} was calculated for each child for a week in summer and winter time.

3.3 Results

The analysis of the time activity profiles obtained shows that the school children spend more than 95% of their time indoors. This percentage slightly decreases in summer and in the weekend. Also, the children living in a suburban location tend to spend more time outdoors than urban children. Figure 4 schematically represents the typical winter and summertime weekday and weekend of the children participating in the study.

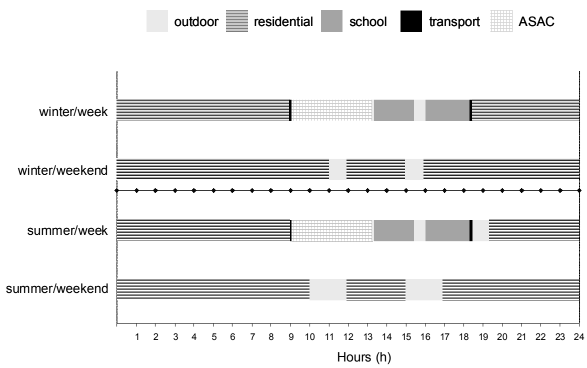

Figure 4: Typical winter and summertime weekday and weekend of the children that participated in the study (ASAC – after school activity centre).

The air quality measurements made at schools outdoor and in the classrooms are shown in Figure 5. During weekdays, the PM_{10} concentrations in the classrooms are significantly higher than in the outdoors for the same location. At urban school Marzovelos, the indoor PM_{10} levels measured during the winter campaign are higher than the double of the outdoor concentrations. At summer, the difference between indoor and outdoor pollution levels is lower. This fact can be explained by presence of indoor emission sources and low ventilation rates at wintertime, while open windows during summertime promote better conditions to indoor/outdoor air exchange. Along weekends, the indoor PM_{10} values are similar to the ones measured outdoor, confirming the existence of indoor PM sources on weekdays.

The model simulations performed are in agreement with the measurements made. They show that the legislated daily value of PM_{10} is often exceed, mainly in winter and in the most urbanised area of the town.

Exposure results are plotted in Figure 6. These results are divided in urban and suburban (according to the children address and school) and winter and summer.

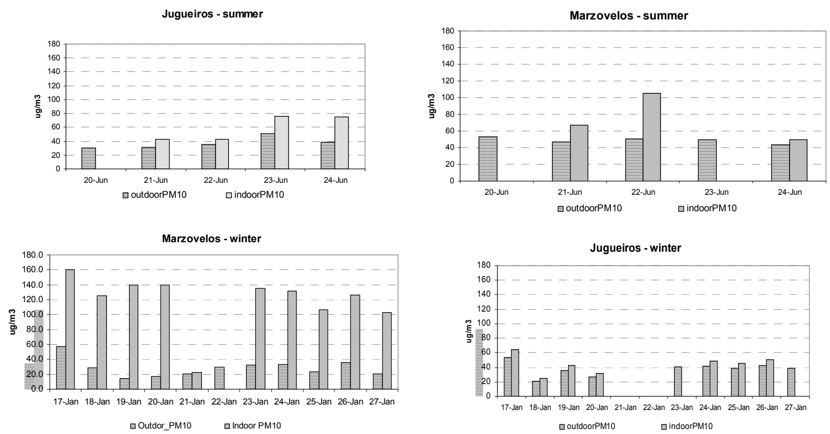

Figure 5: Particulate matter concentration values ($\mu g.m^{-3}$) measured in summer and winter campaigns.

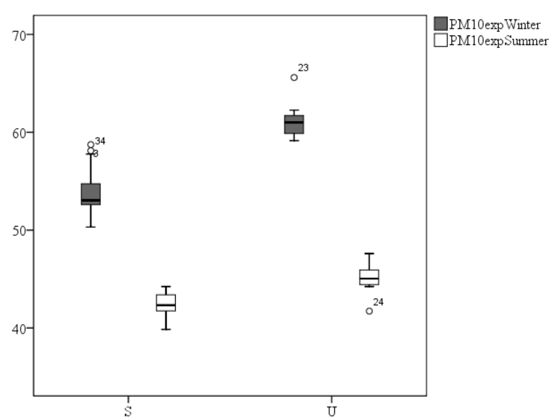

Figure 6: Weekly mean of hourly exposure to PM_{10} ($\mu g.m^{-3}.h$) for urban (U) and suburban (S) children both for winter and summer.

As it can be seen from Figure 6, exposure to PM_{10} is quite high attaining levels of concern, particularly in winter and for the urban location ($61 \mu g.m^{-3}.h$). Although results are calculated for two weeks in a year, they clearly indicate that the annual mean value of 20 $\mu g.m^{-3}$, recommended by WHO [10] is easily exceeded by any of the studied children. The microenvironment that contributes the most to exposure is clearly the classroom.

4 Conclusions

This study intends to contribute for the general knowledge on PM_{10} exposure levels highlighting the importance of their estimation for the definition of air quality standards. Two approaches applied in this work to quantify population and individual exposure have demonstrated the significant contribution of indoor microenvironments to the human exposure by PM_{10} and, therefore, the importance to include indoor concentrations quantification in the exposure assessment. The results of the study show that indoor concentrations could be more than double in comparison with outdoor levels and the individuals are spending more than 90% of time indoors. Besides the contribution of indoor pollution sources, the ventilation of the buildings is also a relevant factor that has to be taken into account. The results indicate the characterisation of indoor pollution sources and indoor PM_{10} levels as a major source of the uncertainty of exposure quantification.

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