FORECASTING HUMAN EXPOSURE TO ATMOSPHERIC POLLUTANTS IN PORTUGAL

C. Borrego[1]*, E. Sá*[1]*, A. Monteiro*[1]*, J. Ferreira*[2]*, A.I. Miranda*[1]

[1]CESAM & Department of Environment and Planning, University of Aveiro, Aveiro, Portugal
[2]University of East Anglia, Norwich, United Kingdom

Abstract: Air pollution has become one main environmental concern because of its known impact on human health. Aiming to inform the population about the air they are breathing several air quality modelling systems have been developed and tested allowing, nowadays, assessing and forecasting air pollution ambient levels in many countries. However, every day, one individual is exposed to different concentrations of atmospheric pollutants as he/she moves from and to different outdoor and indoor places (the so-called microenvironments). Therefore, a more efficient way to prevent the population from the health risks caused by air pollution should be based on exposure rather than air concentrations estimations.

The present study describes the development of a methodology to forecast the human exposure of the Portuguese population, which is based on air quality forecasts available and validated for Portugal since 2005. To estimate the population exposure the forecasting results of the air quality modelling system MM5-CHIMERE have been combined with the population spatial distribution over Portugal and their time-activity patterns, i.e. the fraction of the day time spent in indoor and outdoor places.

The population characterization concerning age, work, type and spent time on occupation/activities, was obtained from the most recent national census and from available enquiries performed by the National Statistics Institute. A daily exposure estimation module has been developed gathering all these data and considering empirical indoor/outdoor relations from literature to calculate the indoor concentrations in each one of the microenvironments considered, namely home, office/school, and leisure activities like shopping areas, gym, theatre/cinema and restaurants. The results show how this developed modelling system can be useful to anticipate air pollution episodes and to estimate their effects on human health. This detailed knowledge is a prerequisite for the development of effective policies to reduce the foreseen adverse impact of air pollution on human health and to act on time.

Key words: *Air quality forecast, human exposure, air pollutants, modelling, human health.*

1. INTRODUCTION

Nowadays, air pollution is seen as a major environmental health problem causing approximately three million deaths per year in the world (WHO, 2001). The emphasis on the management of air quality, especially due to human health effects, has been increasing in the last years, and has recently emerged as a major priority in many urbanised and industrialised countries. This concern coincides with the European Union strategies and the associated national legislation that have been developed.

Air quality forecasting is one of the requirements of the new Air Quality Framework Directive (2008/50/CE) and a key issue of the CAFE Programme. To accomplish this requirement an air quality forecasting system, based on the MM5-CHIMERE modelling system, was developed for Portugal (Monteiro et al., 2005). It is operational since 2005 and forecasts are available and disseminated to the public since 2007. The advantages of reliable air quality forecasts are obvious: population exposure can be more efficiently reduced and protected by means of information, and real-time emission abatement measures can be done.

Human exposure to outdoor air pollution is believed to cause severe health effects, namely where pollution levels often are high, because of the poor dispersion conditions and high density of pollution sources (Hertel et al., 2001). In Portugal high levels of PM_{10} and ozone are currently an important human health concern. However, people spend most of their time indoors and to evaluate the effects of air pollution on human health indoor air quality has also to be assessed. Hence, when evaluating human exposure it is essential to estimate the concentrations of air pollutants not only in open air, but also in different indoor locations, called microenvironments, because people spend most of their time indoors.

Human exposure is defined as an event that occurs when a person comes in contact with a pollutant and exposure estimates to atmospheric pollutants can be addressed to individuals (personal exposure) or large population groups (population exposure), and can be based on direct (exposure monitoring) or indirect methods (exposure modelling). Numerical modelling applied to exposure studies should integrate indoor and outdoor air pollutants levels. The levels of indoor concentrations are caused by the existence of indoor sources and/or for influence of outdoor concentrations. The relationship between indoor and outdoor concentrations is often considered in terms of indoor to outdoor (I/O) concentration ratios. There are several parameters affecting the I/O ratio, such as penetration factor, deposition rate, and air exchange rate, which are greatly uncertain (Borrego et al., 2006). The general approach for exposure estimation can be expressed by (BEST, 1994):

$$Exp_i = \sum_{j=1}^{n} C_j t_{i,j} \tag{1}$$

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 aims to create a link between the air quality forecast and human exposure, contributing to a better comprehension of the theme Environment-Health. For that, a module to calculate the human exposure has been developed for Portugal and incorporated in the forecasting system. The human exposure associated to the forecasted air quality is predicted using the concentrations of pollutants simulated by the forecasting system, bibliographic indoor/outdoor relations and the time-activity profile of the Portuguese population. This integrated air quality-exposure forecasting system was tested for the 2007 year and the results are presented.

2. THE FORECASTING SYSTEM

The air quality modelling system

The air quality modelling system is composed by the chemistry-transport model CHIMERE, forced by the MM5 meteorological fields (Monteiro et al., 2005). CHIMERE, the 3D chemistry transport model, based on the integration of the continuity equation, was developed specifically for the simulation of gas-phase chemistry, aerosol formation, transport and deposition at European and urban scales. Meteorological input variables given by the MM5 model are: 3D fields of horizontal wind, temperature, specific humidity, cloud liquid water content, and 2D fields of surface pressure, heat fluxes, 2 m temperature and cloud cover. They were linearly interpolated to the CHIMERE grid. Besides meteorological input data, CHIMERE model requires definition of boundary and initial conditions, emission data and the land-use and topography characterization.

The model system is applied using a simple one-way nesting technique. A first continental-scale run is performed with CHIMERE over a regional area from 10.5W to 22.5E and from 35N to 57.5N with a 50 km grid resolution, followed by a nested simulation over Portugal domain of 290×580 km^2, with a 10 km grid resolution (Fig. 1a).

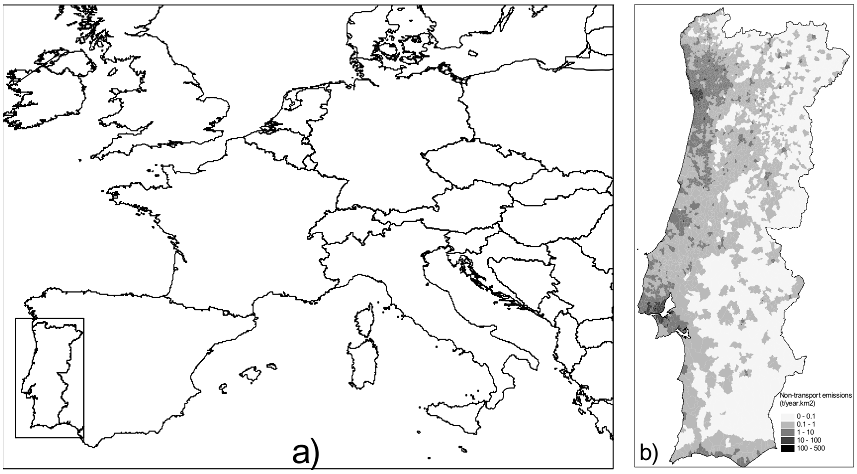


Figure 1. (a) Domains used on the air quality simulation; b) Area sources (non-transport) emissions field used for Portugal domain.

The CHIMERE model uses the same physics approach for the two domains simulations. Eight vertical layers above topography are considered, the first one (the surface layer) having a depth of 50 m. The model top lies at 500 hPa. The continental run is forced at the lateral and top boundaries by monthly climatology of species concentration issued by the GOCART second-generation model (Ginoux et al., 2001). The lateral boundaries of the small-scale domain (Portugal) are taken from the large-scale run species concentrations (including ozone and its precursors) and the top boundaries as the GOCART monthly climatological values. The model simulates the concentration of 44 gaseous species and six aerosol chemical compounds. The gas-phase chemistry scheme has been extended to include sulfur aqueous chemistry, secondary organic chemistry and heterogeneous chemistry of HONO and nitrate. The aerosol model accounts for both inorganic and organic species, of primary or secondary origin, such as primary particulate matter, sulfates, nitrates, ammonium, secondary organic species and water. The population of aerosol particles is represented by a sectional formulation. The model version used here is primarily described in Schmidt et al. (2001) and further updates can be found in Bessagnet et al. (2004).

At the European scale, emissions were derived from the annual totals of the EMEP database for 2003 using a methodology similar to that described in Schmidt et al. (2001). Over the Portuguese domain, area-sources annual emission data are obtained from the Portuguese national inventory for the most recent year (2003), by different pollutant source activity. The emissions were then spatially downscaled to the sub-municipality level for each activity sector (Monteiro et al., 2005). Figure 1b) shows one example of the spatial distribution of annual emission for Portugal. Large point sources annual emissions are obtained directly from each industrial plant database. Emissions time disaggregation is obtained by application of monthly, weekly and hourly profiles from the GENEMIS project

(1994). The NMVOCs are disaggregated into 227 individual VOCs according to the U.K. speciation (Passant, 2000). The methodology for biogenic emissions of isoprene and terpenes is described in Schmidt et al. (2001).

The forecasting system is designed to be as simple as possible in order to fit the real-time constraints and to deliver forecasts in the early morning for the same and the next 2 days. Meteorological forecasts are obtained at date D+0 using the MM5 mesoscale meteorological model forced by the AVN/NCEP global forecasts. Every day (D+0) the forecasts start the day before (D-1) at 00UT and run until Day+2. These meteorological forecasts are carried out with an effective resolution of 9 km and 25 vertical sigma levels. Processed meteorological variables are then provided to CHIMERE, as well as the emissions. The chemistry-transport model is initialised at 00 UT on Day-1, using the previous 24 hour forecast, without any use of observations. The model then produces the air quality forecasts, for 4 different lead times: Day+0 (forecast for the day), Day+1, Day+2, and Day-1. This latter lead time is based on "first guess meteorological fields" until 12 UT for the first simulation day and on forecasts thereafter itself. Once all these calculations are achieved, the air quality outputs are delivered on a web server (http://www.dao.ua.pt/gemac/previsao_qar) in the form of graphics.

The human exposure module

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 indoor/outdoor relations and the variation of the concentrations in each microenvironment. The original data, with municipality level resolution, were transformed to regular grids correspondent to the simulation domain (10x10 km^2).

The resident population, in each municipality, and their occupation time daily profiles were obtained from the 2001 Census data of the Portuguese National Statistics Institute. Matrixes of daily time-activity pattern per microenvironment have been defined, on an hourly basis, for the population of Portugal for the weekdays and weekends (Figure 2). According to the detail of information gathered it was possible to consider four different microenvironments, namely, home, work/school, other indoors (restaurants, indoor gym, shopping mall, cinema/theatre) and outdoor.

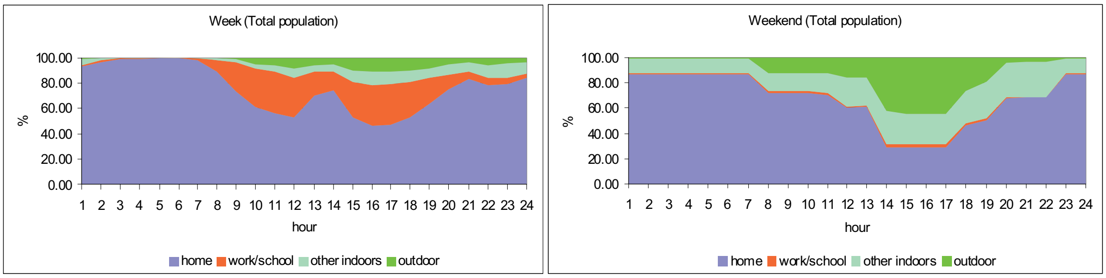


Figure 2. Input data of human distribution for exposure module to estimate population exposure in Portugal.

The exposure module calculates the indoor concentrations using the outdoor concentrations simulated by the numerical forecasting system considering empirical indoor/outdoor relations obtained from literature applied to Portugal. The selected relation values are summarised in Table 1. Outdoor concentrations are superior to indoor values, in particularly in the winter period. NOx presents the closest indoor/outdoor concentrations, suggesting the existence of indoor emission sources.

Table 1. Indoor-Outdoor relations considered in the human exposure module (Poupard et al., 2004; Baek et al., 1996; Lee et al., 1997; Dimitroulopoulou et al., 2006; Chau et al., 2001; Wallace et al., 2005; Franck et al., 2003; Hanninen et al., 2004; Lazaridis et al., 2003)

	Microenvironments					
	Home		Work/school		Other indoors	
	Summer	Winter	Summer	Winter	Summer	Winter
O_3	0.60	0.40	0.80	0.60	0.80	0.60
NO_x	0.80	0.70	0.85	0.75	0.90	0.80
PM_{10}	0.75	0.65	0.80	0.70	0.80	0.70
$PM_{2.5}$	0.60	0.48	0.80	0.70	0.90	0.80

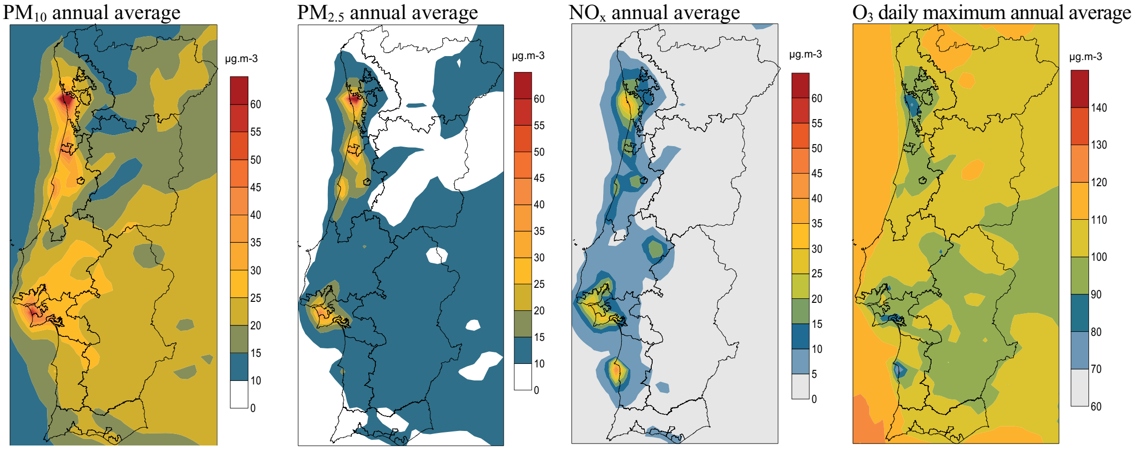
3. RESULTS

The air quality-exposure integrated forecasting system has been applied for the year 2007, over the Portugal domain (Fig. 1a) with a 10 km horizontal resolution. The hourly exposure results have been treated in order to obtain a long-term estimation of the human exposure forecasted during this period.

The spatial distributions of concentration values and the total population exposure to the main critical pollutants - NO_x, PM_{10}, $PM_{2.5}$ and O_3,- are shown in Figure 3 in terms of annual averages for the 3 first pollutants and annual maximum daily values for O_3. For NO_x, PM_{10} and $PM_{2.5}$ both, concentration and exposure fields, present the highest values for the two main Portuguese urban centres, Lisbon and Porto, where emission sources and population are concentrated. In what concerns O_3, the concentration pattern differs significantly from the exposure field, since the first do not exhibits the highest values in the urban areas, but downwind (due to transport and photochemistry phenomena), where population density is smaller.

These results suggest that these two areas should be identified as the most critical ones in terms of air pollution (gaseous and particulate) and its effects on human health over Portugal. The coexistence of high concentration values and high population density is the key factor for these stressed areas.

Concentration values



Exposure values for total population

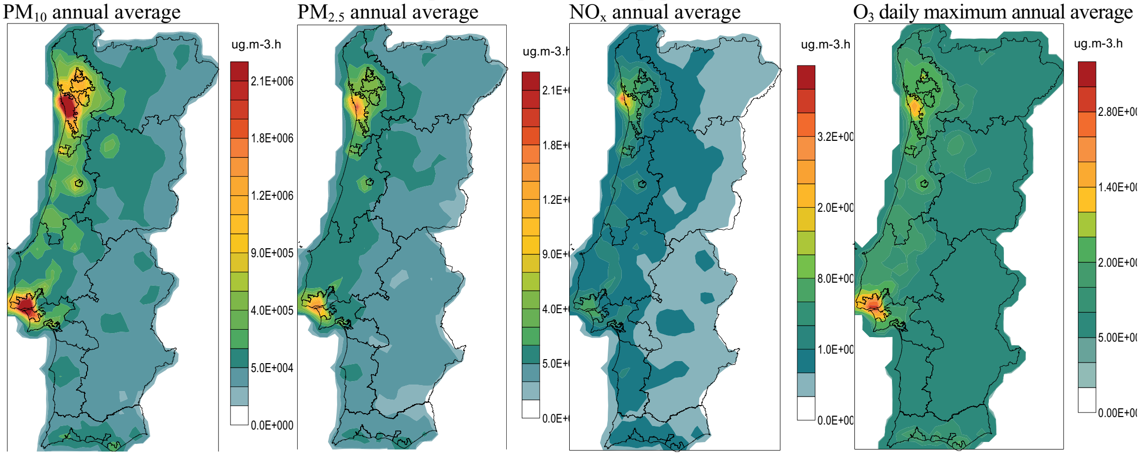


Figure 3. Annual average fields of NO_x, PM_{10}, $PM_{2.5}$ and O_3 concentration and human exposure values for the study domain.

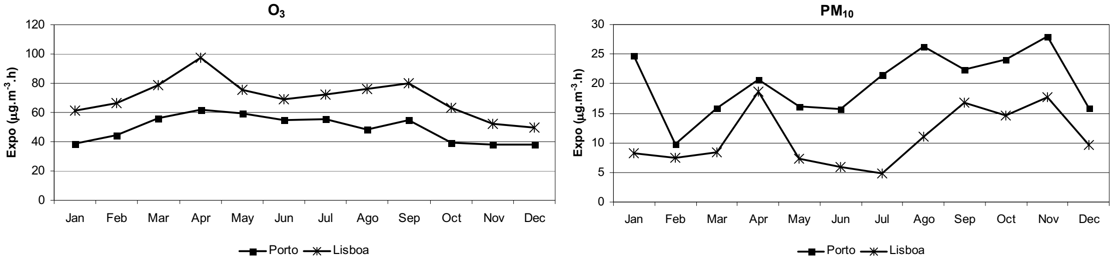


Figure 4. The temporal variation of the monthly averaged individual human exposure for O_3 and PM_{10} for Porto and Lisbon areas (2007).

Individual exposure (per inhabitant) can also be estimated based on these results. The monthly averaged individual exposure values for Lisbon and Porto are presented in Figure 4, for O_3 and PM_{10} along the year 2007.

The temporal profile obtained for ozone human exposure is justified by the more intense photochemistry activity in summer months. For PM_{10}, there is no obvious trend during the entire year, besides some peaks in spring and winter. Human exposure is higher over Lisbon, regarding O_3, but concerning PM_{10} Lisbon presents smaller values. In this sense, it is not possible to identify, between the two cities, the most affected one in terms of air pollution, since it depends on the type of pollutant analysed.

4. CONCLUSIONS

The methodology developed in this study can be very important for the forecasting of human exposure to atmospheric pollutants in Portugal in order to link the assessment of the air quality to a more efficient protection of human health.

The modelling results suggest that the areas of most concern for population exposure levels, regarding primary pollutants, in Portugal, are the major urban areas (Lisbon and Porto). Nevertheless, high values for human exposure, regarding O_3, are expected in the surroundings of urban areas and rural regions.

Different pictures and conclusions should be addressed when human exposure is analysed in terms of total population or individually (per inhabitant). Nevertheless, due to coexistence of both factors – pollutants concentration and population density - the two urban centres of Lisbon and Porto are identified as the most stressed areas in terms of air pollution and effects on human health. Here, higher exposure values for O_3 were forecasted over Lisbon and higher values for PM_{10} in Porto region.

For the authors, the methodology developed for population exposure estimation over Portugal is the main goal to retain because the uncertainty of results greatly depends on the input data used. The lack of more detailed information for Portugal regarding the population characterization in terms of time-activity patterns and the spatial distribution of microenvironments has implied the consideration of approaches and assumptions to make possible to forecast the human exposure. Nevertheless, this application can be useful to the health organizations to predict the human exposure and take real time actions to reduce human health effects resulting from air pollution episodes. Besides that, the module developed is a valuable and independent tool to estimate human exposure and thus can be incorporated on different air quality models, allowing its use on different studies and modelling systems.

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