Filling the gap between air pollution and human health: from emissions to dose assessment

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1. Introduction

Protecting human health of communities and promoting the wellbeing of individuals are common concerns and aspirations of researchers, practitioners, policy makers and general population. Common efforts towards the assessment of environment impacts on human health, namely regarding air pollution, have been done during the last decades. Road traffic, industrial activities and fossil fuels used on energy and house heating represent the most important sources of air pollutants, especially in urban areas. Hence, natural events as mineral dust transported from deserts and forest fires contribute significantly to the quality of the air in southern Europe.

Air pollution affects human health and is the cause of around three million deaths per year. Among the global population, there are groups particularly vulnerable to the impacts of air pollution such as the elderly, the chronically ill, the children and people with activities that take place in particularly exposed locations (professional drivers, industrial workers, firefighters). In this context, this paper will present the methodologies and results of three research studies carried out in Portugal (SaudAr and FUMEXP projects already concluded, and the on-going INSPIRAR project), as a joint collaboration between environmental and medical experts, attempting to answer to the questions: How does air quality affect the exposure and health of children? Are asthmatics more vulnerable to air pollution than healthy children? How does smoke from a forest fire affect the health of firefighters? Are industrial workers more likely to suffer the effects of the air they breathe than other professionals? These questions cannot be answered by tackling only air pollution, because air quality, alone, is not an accurate environmental health indicator.

2. From Air Pollution to Human Health

The effects of atmospheric pollution on human health are the result of a chain of events (Figure 1), starting on the pollutants emission, going through transportation, dispersion in the atmosphere and by the individual inhalation (inhaled dose). The evaluation of those effects implies the knowledge of the several chain links.

Figure 1. Chain of events associated with atmospheric pollution, from emission to health effects.

Human exposure can be defined as an event that occurs when an individual is in contact with a pollutant (Duan, 1982; Ott, 1982). The European legislation recognizes and recommends to use human exposure as an assessment indicator of health impact. To have exposure it is required that the concentration of a pollutant (a physical environmental characteristic) in a certain location is not zero, and simultaneously, an individual is present in that location (Sexton and Ryan, 1988). The definition of exposure refers to an instantaneous occurrence between a person i and a concentration pollutant c, for a certain period of time. Exposure does not necessarily imply a pollutant inhalation or ingestion; it is only related with the pollutants levels in the environment. On the other hand, the dose concept is used when a pollutant crosses the physical barrier (body). When analysing the exposure to atmospheric pollutants, the inhaled dose is referred as the amount of pollutants inhaled by an individual in a determined time.

Different methodologies can be applied to determine the individual exposure, using direct measurements or estimations based on exposure concentration data and the time of contact. The general approach for exposure estimation can be expressed by (Hertel et al., 2001): $Exp_i = \sum_{j=1}^{n} C_j t_{ij}$,

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where Exp_i is the total exposure for the 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. The calculation of the inhaled dose is conducted recurring to the following equation: $Dose_i = C_j * t_{ij} * V_{ij}$, where V_{ij} is the person ventilation rate i in the microenvironment j.

Exposure can be used to infer health effects by the study of dose-response relationships. These correlations can be established by the simultaneous determination of individual exposure and associated health effects. Medical tests are performed to evaluate the respiratory function of a person which is quantified by the following parameters: pH, NO, CO, % carboxy-haemoglobin (COHb) measurements on the breath condensate, broncodilation test with spirometry, urinary cotitin measurements, forced expiratory volume in 1 first second (FEV1), forced vital capacity (FVC), ratio FEV1/FVC, peak expiratory flow (PEF), flow at 50% of FVC (F50), forced expiratory flow between 25–75% of FVC (F25), mid-expiratory flow rate (MEF). These health indicators allow identifying short-term cause-effect relations as a contribution to the assessment of air pollution impacts on human health.

3. Case studies

3.1. Air Pollution and health effects in school children

The SaudAr project focused on the influence of air quality on the asthmatic disease, by establishing a relation between the levels of human exposure to atmospheric pollution and the respiratory health of a selected group of children. With this objective, several field campaigns were conducted involving outdoor and indoor air quality measurements and medical examinations (Borrego et al., 2009).

The studied population covered a total of 50 children, from four elementary schools (two located in the town centre and the other two in the city suburbs) in the city of Viseu (inland Portugal), that were susceptible to respiratory diseases, such as asthma or allergies, making possible the analysis of the response of their health to air pollution episodes. The group of children was chosen by the application of the ISAAC - International Study of Asthma and Allergies in Childhood - questionnaire to 805 children.

Four dedicated field campaigns of one week duration took place on the summer and winter of 2006 and 2007. Outdoor and indoor air quality at the city of Viseu was evaluated using monitoring devices for the most important atmospheric pollutants: particulate matter (PM10), carbon monoxide (CO), volatile organic compounds (VOC), nitrogen oxides (NO_x), sulphur dioxide (SO_2), ozone (O_3), BTX (benzene, toluene and xylene) and formaldehyde. In particular, PM10, NO_x, SO_2, CO and O_3 pollutants were measured continuously at three mobile laboratories (Figure 2c), whereas NO_x, O_3, BTX and formaldehyde were evaluated using passive samplers (Figure 2b) at 20 points distributed over the town of Viseu, and also at 44 indoor points (including children houses and the selected schools).

a b c

Figure 2. Monitoring during field campaigns: (a) children's health evaluation at the local hospital; (b) outdoor air pollutant measurement using passive samplers; (c) mobile air quality laboratory with high-volume PM samplers.

The children attended the local hospital where the medical research team carried out several examinations: skin prick tests, pH measurements on the breath condensate, online measurements of NO in the exhaled air, broncodilation test with spirometry, urinary cotitin measurements and monitoring of the PEF (Figure 2a).

The exposure and dose quantification was determined separately for each individual under the study. For this purpose, two main tasks have been carried out: a) the definition of the daily activity profile of each child for a typical winter and summer school week, through personal enquiries to parents and children, 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 air quality assessment in the identified microenvironments, both outdoor and indoor, has been performed using a multi-strategy approach: measurements during field campaigns and air quality modelling simulations. Table 1 shows the average values of individual exposure and inhaled dose to the three selected atmospheric pollutants during a regular winter and summer week.

Table 1. Averaged individual exposure and inhaled dose to atmospheric pollutants during the summer and the winter periods.

Pollutant	Summer exposure (μg.m^{-3}.h^{-1})	Winter exposure (μg.m^{-3}.h^{-1})	Summer inhaled dose (μg.h^{-1})	Winter inhaled dose (μg.h^{-1})
PM_{10}	50.5	56.3	19.3	20.8
O_3	34.0	15.6	10.7	5.4
NO_2	10.0	15.3	3.2	5.1

According to the measured air quality levels, PM10 was considered the pollutant with more concern regarding exposure. In fact the calculated exposure to this pollutant is above 50 μg.m^{-3} for both summer and winter weeks, that is considerably higher than the value of 20 μg.m^{-3}, the WHO annual threshold for the protection of human health. It was also found that the children attending the city centre schools are more exposed to this pollutant (Valente et al., 2008). Through the analysis of the inhaled dose results it was possible to conclude that the different levels of human activity during the day influence the levels of inhaled dose, for children with similar exposure levels to air pollutants.

Aiming to find a relation between exposure, dose and health effects, an exploratory analysis of the variables of interest was carried out. Chi-square test was used to compare proportions and Friedman's test to compare pollutants, weather conditions, spirometric and inflammation outcomes along the four campaigns (Martins et al., 2012). Results revealed that the increasing mean personal exposure to PM10 in the studied week was associated with a trend of deterioration of airways, reaching significance with a decrease of the FEV1 and increase of ΔFEV1. Associations were found also for an increase of NO_2 exposure: a decrease of FEV1, FEV1/FVC, F25, pH on EBC and an increase of ΔFEV1. No associations were achieved for O_3. Exposure to PM10 as estimated using a function of both concentrations and daily activity patterns was related to lung function decline, even in a non-industrial city like Viseu (Martins et al., 2012).

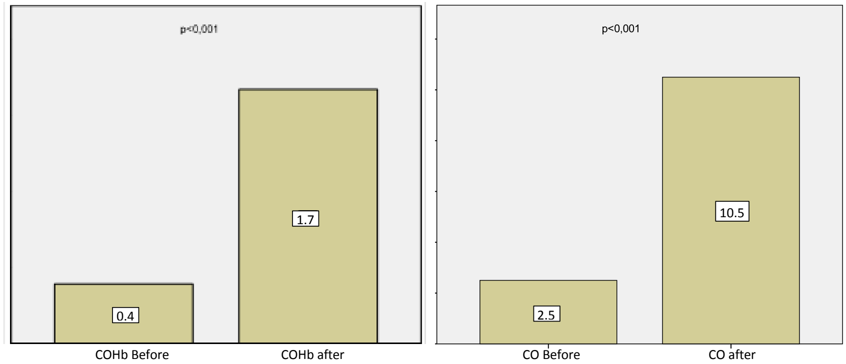
3.2. Air Pollution and health effects in firefighters

The impacts of smoke from forest fires on air quality and human health can be significant since large amounts of pollutants, like particulate matter (PM), CO, VOC and NO_x are emitted to the atmosphere. There are a number of factors that affect the health impacts of smoke, including concentration of air pollutants within the breathing zone of the firefighter, exposure duration, exertion levels, and individual susceptibility such as pre-existing lung or heart diseases (Reisen and Brown, 2009). Another major factor influencing exposure is the type of work activities that firefighters carry out and their position relative to the fire during those activities. Adverse health effects occur with acute, instantaneous, eye and respiratory irritation and shortness of breath, developing into headaches, dizziness and nausea lasting for hours, and mild impairment of lung function for hours to days (Reinhardt et al., 2000). In this context the national research project FUMEXP (2008-2010) aimed to analyse the potential effect of forest fire smoke on firefighters health in Portugal, based on the estimation of the firefighters personal exposure to air pollutants through measurements of fire behaviour characteristics, air pollutant levels and personal exposure during experimental fires and wildfires. Medical tests performed on selected firefighters allowed the analysis of the potential health injuries resulting from this activity (Miranda et al., 2010, 2012).

In the scope of FUMEXP, ten firefighters, from different central districts in Portugal, including Leiria, Coimbra and Aveiro, were chosen to be monitored for their individual exposure to smoke emitted during wildfires. They were equipped with personal devices for CO, VOC and NO_2 monitoring (Figure 3a) during their activities in 11, 13 and 28 wildland fire operations, in 2008, 2009, and 2010 fire seasons respectively. These fires were fully characterized in terms of fire behaviour, meteorological and air quality conditions. Firefighters were medically evaluated before and after the 3 year period regarding their respiratory function through different spirometry parameters (FEV1, FVC, Ratio FEV1/FVC, PEF, F50, F25, MEF) (Miranda et al., 2012). Hence, before and after every firefighting event, NO, CO and COHb in the exhaled breath were also measured.

Exposure results were compared to the occupational exposure standards (OES) defined for different air pollutants: (i) threshold limit value (TLV) of the time-weighted average (TWA); (ii) TLV of the short-term exposure limit (STEL); and (iii) peak limit. There were several exceedances to the TWA, STEL and peak values for CO. The CO peak limit concentration was exceeded 40% of the time for the 52 reported occurrences and for 67% of them more than once. The highest CO peak limit observed was 1,000 ppm. The STEL also exceeded the TLV for nearly 19% of the monitored situations (Miranda et al., 2012).

The respiratory function of the 35 firefighters in April 2008 and at the end of the 2010 fire season was compared and results indicate that the firefighters experienced a reduction of their respiratory function between the two evaluations. Figure 3b illustrates the changes in the CO and COHb values measured just before and after the exposure to smoke in 2010 wildfires. There was a strong increase of the exhaled CO and COHb after the exposure to smoke, meaning that the O_2 delivery to the body's organs and tissues is strongly diminished after smoke exposure.



a b

Figure 3 – (a) Firefighter with the exposure monitoring equipment. (b) Exhaled COHb and CO (ppm) values measured just before and after exposure to smoke in 2010 wildland fires.

This work indicates that forest firefighting can expose firefighters to very high concentrations of CO, and also to high concentrations of NO_2 and VOC, with potential harmful effects on their health, even in wildfires with small burnt areas. A particular concern is the peak and short-term exposure to CO. It is not easy to establish a direct relationship between smoke exposure and health respiratory indicators, but results point to an increase of exhaled CO when a higher exposure to CO happens and a decrease of exhaled NO when the exposure to NO_2 is higher.

3.3. Air Pollution and health effects in an urban industrialized area

The intense industrial development from the second half of the 20th century, coupled with population growth and population concentration in urban areas has accentuated the concern on the evaluation of the potential effects and impacts from air pollutant emissions on environment and human health. The contribution of industrial activity has not been properly accounted for, in contrast to other sources (e.g. road traffic). Thus, industrialized urban areas present increased challenges, due to the type of pollutants involved (in particular those of industrial origin) and the lack of information on exposure to short and long term and their relationship to population health. INSPIRAR project, launched in March 2010, aims to develop a multidisciplinary methodology for air quality, exposure and population health impacts assessment, from the emission of industrial pollutants in an industrialized urban area. The methodology will be applied to Estarreja region, an urban area that has one of the largest chemical complexes in Portugal, and consists on the implementation of modelling tools to quantify industrial air pollution and human exposure of two different groups - industrial workers and general population. To establish the link between exposure and health effects an epidemiological approach, including a medical evaluation, is considered.

The contribution of industrial activities to the atmospheric emissions in the study region is relevant, accounting around 80% of total emissions in the municipality of Estarreja. In the air quality assessment performed for the period 2000-2009, exceedances to limit and target values of SO_2, PM10 and O_3 concentrations were verified. Most critical pollutants like PM10 and O_3 surpass the regulated standards consecutively. Air pollution episodes can be related either with local emissions (industry and traffic) and specific meteorological conditions, or with advection and long range transport (Lopes et al., 2012).

Contacts with local governmental, educational and medical entities, and protocols with the industrial enterprises involved have been established aiming to gather volunteers to form the two desired groups of the population. Two medical field campaigns, in May-June 2011 and February-March 2012, were already carried out, in which volunteers have answered to a medical and a diary questionnaire to characterize their health condition and history and their weekly activity pattern and have performed a spirometry to evaluate their respiratory function. From a total of 500 industrial workers of 4 different industries, 185 (37%) have participated in the campaigns. The control group, tentatively similar in age range and masculine vs feminine ratio, was constituted by 176 and 226 individuals in the 1st and 2nd campaigns respectively. The medical results will be analysed in combination with individual exposure and dose quantification aiming to study whether the industrial activity as a professional occupation has implications on the industrial workers' health compared with other people working in the region.

4. Final Remarks

The effects of air pollution on health are dependent on several factors. Apart from the concentrations and chemical properties of the pollutants, the person's age and general state of health, the duration of exposure, factors such as the weather condition and the distance from the emission sources also affect the nature and extent of the health effects observed. Health impacts may be greater for individuals and groups that are more susceptible, more exposed, or otherwise more vulnerable. This paper presents three health impact studies addressing different sub-groups of the population with distinct vulnerability to air pollution health effects: asthmatic children, that are more vulnerable due to age (intrinsic factor) and pre-existing disease (acquired factor), firefighters and industrial workers, potentially more susceptible in view of their occupation (acquired factor).

Regarding wheezing children, results suggest a relation between total exposure to air pollutants assessed in various environments and airways changes. Attention should be dedicated to air quality in houses and schools in childhood as most part of the children's time is spent in these environments and to volatile organic compounds as these pollutants seem to have an impact on airways even at low concentrations.

The individual exposure measurements to firefighters during 3 fire seasons demonstrated that they can be exposed to high levels of air pollutants, namely carbon monoxide and PM2.5 with potential harmful effects on their health, even on relatively small prescribed fires and wildfires. These results indicate that urgent measures to avoid these levels of exposure are needed

Concerning the sub-group of industrial workers, preliminary results reveal that the human exposure to air pollutants is not higher for the Estarreja industrial complex workers than for the general population, once the air quality in the region is influenced by both local emissions and transport from other areas. However, the data collected during the medical campaigns are still being analysed.

The methodologies developed under these studies, to fill the gap between air pollutant emissions and the inhaled dose, are examples of cooperation between different fields of research towards a healthier life and should be considered in systematic environmental Health Impact Assessments. The results contribute to better comprehend the impact of air pollution on human health and to improve the quality of life of populations. Future research areas to clarify the links between air pollution and respiratory effects should include a control group and a multipollution approach. New data have shown that multipollution is an important phenomenon to be taken into account in the assessment of health effect of air quality. Better understanding of population vulnerability can improve the scientific basis to assess risks and develop policies or other health protection initiatives to reduce the impacts of air pollution.

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