The use of air criteria pollutants in analysing long-term exposure health risks

P. Morra, G. Spadoni
University of Bologna,
Department of Chemical, Mining and Environmental Engineering
Via Terracini 28 – 40131 Bologna – ITALY

Recent epidemiological studies evidenced that exposure to ambient air pollution is linked to several health outcomes from morbidity to mortality. National regulations define air quality standards for the so called 'criteria pollutants' and a reduction of these threshold levels is scheduled in order to obtain health benefits. A number of authors proposed concentration-response (C-R) functions to predict the health effects linked to the presence of criteria pollutants in air. The paper examines the C-R functions applicability and compares different studies available in literature outlining the uncertainties typical of these kind of epidemiological studies. In particular health benefits are analyzed as a consequence of NO_x and PM_{10} concentrations reduction in a realistic case study.

1. Introduction

Criteria pollutants are the compounds usually considered as good indicators of air quality: sulphur oxides, nitrogen oxides, particulate matter, lead, carbon monoxide and ozone. The main sectors emitting air criteria pollutants are road transport, power and heat production sectors, industry and agricultural.

This group of hazardous air pollutants are known or suspected to cause adverse health effects in humans exposed to them, as increases in daily mortality, hospital admissions and emergency room attendances for respiratory and cardiovascular disease.

Quantifying the impact of air pollution on the public's health has become an increasingly critical component in policy discussion because of the difficulties in determining exposure–response relationships. In last years several epidemiological studies concerning exposure to criteria pollutants have measured increases in mortality and morbidity with the aim to establish their chronic toxicity level, but the results are affected by multiple uncertainties most of them related to heterogeneity in population categories and epidemiologic extrapolation methods. Sources of heterogeneity include different exposure profiles, climate and individual population sensitivities to exposure. Effects difficult to be accounted in epidemiological studies results are the other influences on health outcomes, as smoking, meteorological events and simultaneous exposure to several pollutants.

At low pollution levels health effects are difficult to detect; epidemiological studies must be carefully designed and executed following appropriate protocols and standards. The results also require appropriate statistical analysis and interpretation in the context of a large amount of scientific data and information. In particular the application of results of epidemiological studies in regions different from the one examined in the studies, call for a careful selection of data and a critical interpretation of resulting outputs that take into account also all confounders factors involved in the analysis.

2. Criteria pollutants

2.1 Regulations

National laws establish for each of the criteria pollutants a maximum concentration that cannot be exceeded if the human health must be protected. In Italy the in force regulations, in accordance with European directives, define air quality standards and alert thresholds for sulphur oxides, nitrogen oxides, particulate matter, lead, benzene, carbon monoxide (D.M. 60/2002), and ozone (D.Lgs. 183/2004).

According to WHO (WHO, 2004) and EPA (U.S.EPA 1999; U.S.EPA 2003) studies many different adverse effects have been linked to exposure to air pollution, including an increased risk of cardiopulmonary disease and a reduction in life expectancy of a year or more for people living in European and U.S. cities. Some of these effects occur at very low concentrations that were previously considered safe. Taken together, the evidence is sufficient to strongly recommend further policy action to progressively reduce levels of criteria air pollutants. It is reasonable to assume that a reduction in air pollution will lead to considerable health benefits. For these reasons EU policy-making on air quality (EC, 2005), in particular the Clean Air for Europe (CAFE) programme of the European Commission is gradually reducing air quality standards for several polluting compounds.

2.2 Epidemiological studies

According to WHO researches (WHO, 2000; WHO, 2006), in the past the concept of no-effect thresholds played an important role in deriving air quality guidelines. The existence of such thresholds implies no effects of increasing air pollution until a "threshold" concentration is surpassed, at which stage risk rises. Nevertheless, recent epidemiological studies investigating large populations have been unable consistently to establish such threshold levels, in particular for PM and ozone. Instead of thresholds, exposure/concentration–response relationships for different health end-points provide more realistic information for taking effective action to reduce adverse effects on human health.

Therefore, even if the limit value is not exceeded, health impacts, including in some cases a substantial reduction in life expectancy, are to be expected. As a matter of fact, several studies performed in the United States and European countries evidenced a strict association between air pollutants levels of concentration and the daily number of deaths or hospital admissions for respiratory or cardiovascular causes.

Adverse health effects are usually considered as a consequence of short-term and long-term exposure. The short-term exposure effects are evident in population exposed in days where the pollutants concentration is higher: aggravation of respiratory and cardiac symptoms in susceptible individuals, acute respiratory infections, bronchial asthma, circulatory and ischemic disease. The long-term effects are detected as a consequence of a long period exposure: chronic pulmonary effects, cardiopulmonary diseases, death or reduction in life expectancy, ecc.

Epidemiological studies have shown that some population groups are more susceptible to the effects of air pollution. These include children, the elderly and those with pre-existing health conditions such as asthma, chronic obstructive pulmonary disease and ischemic heart disease. Young children, in particular, are among the most susceptible to effects of air pollution (WHO, 2005).

Data resulting from epidemiological studies are affected by several uncertainties mostly related to confounders factors that are smoking status, diet and occupation of exposed individuals, weather factors. Therefore the shape of exposure–response relationship curve explored in both Europe and the United States varies between locations. Sources of heterogeneity include different exposure profiles, climate and individual population sensitivities to exposure.

3. The assessment of adverse health effects

The typical approach to model the incidence of adverse health effects resulting from exposure to air criteria pollutants requires three types of inputs:

(1) estimates of the changes in air quality ;

(2) estimates of the number of people exposed to air pollutants at a given location;

(3) concentration-response (C-R) functions that link changes in air pollutant concentrations with changes in adverse health effects.

In particular the approach makes use of Concentration-Response functions specific of each adverse health effect (premature mortality, heart and cardiovascular disease, respiratory illness), that relate the change in the number of individuals in a population exhibiting a response to a change in pollutant concentration experienced by that population. These functions likely depend on the activities of the population living in the territory.

In order to analyse quantitatively the impact on health of outdoor air pollution in a specific city, region or country, usually the application of C-R functions call for information related to background incidence of mortality and morbidity associated to background levels of criteria contaminants concentrations. Besides, analysts should be aware that baseline morbidity and mortality rates will change over time.

The choice of which health outcomes to include in the assessment may be determined by the strength of available studies and the accessibility of health information.

The quality of the risk assessment depends on: (*a*) the accuracy of the C-R functions; (*b*) how applicable these functions are to locations and times other than those for which they were originally estimated; (*c*) the extent to which the C-R functions apply beyond the range of concentrations for which they were originally estimated; and (*d*) the number of health outcomes specified. The selection of the most appropriate C-R-functions should be based on the following criteria: peer reviewed and up-to-date studies, chronic exposure research, large sample of study populations, study location, several typologies of contaminants included in the study.

The health effect, denoted as y (defined as the probability of a human being to suffer that health effect in a defined time-span), is estimated at a single location where a change in air quality ΔC corresponds to a change in the health endpoint Δy.

The evaluation of the relationship between the contaminant concentration and the health effect depends on the choice of the functional form of the relationship and on the values of the parameters assumed in the function. The log-linear and the linear relationship are the most common functional forms found in the epidemiological literature.
The log-linear relationship is of the form:

$$y = B \cdot e^{\beta \cdot C} \tag{1}$$

where
B = incidence of y when the concentration is zero (probability at background level)
β = coefficient
C = concentration of the criteria pollutant

The relationship between Δy and ΔC is usually described as follows:

$$\Delta y = y_{before\,change} - y_{after\,change} = y_{before\,change} \cdot \left[1 - e^{-\beta \cdot \Delta C}\right] = y_{before\,change} \cdot \left[1 - RR_{\Delta C}\right] \tag{2}$$

where
$y_{before\ change}$, $y_{after\ change}$ = health effect before and after the change in C
$\Delta C = C_{baseline} - C_{after\ change}$

Note that Δy greater than 0 means a reduction of health effects probability, i.e. an increase of health benefits.
The Relative Risk (RR) associated with the change in contaminant concentration is :

$$RR_{\Delta C} = \frac{y_{after\,change}}{y_{before\,change}} = e^{-\beta \cdot \Delta C} \tag{3}$$

If epidemiological studies report the relative risk associated to a given change in contaminant concentration, the C-R function coefficient β can be easily derived.

4. The case-study

In this paper an hypothetical but realistic area in Italy characterized by sources emitting typical air criteria pollutants (industrial stacks, road traffic, building heating systems) is examined as a case-study, in order to evaluate the impact of the use of C-R functions in a territory and to discuss about their applicability in a territory different from the one examined in the epidemiologic study.
The analyzed territory is a urban centre of about 64 km^2. Air polluting is caused by different typologies of emission sources: heating area sources, road traffic linear sources and stacks point sources. Air dispersion modelling is applied to evaluate the concentration of contaminants and spatial distributions are represented in georeferenced maps as a measure of population exposure. Among emitted criteria pollutants, PM_{10} and NO_x are examined, because of their most serious adverse health effects.
In force Italian legislation provides a threshold annual concentration for PM_{10} of 40 $\mu g/m^3$ at the year 2005 and 20 $\mu g/m^3$ at the year 2010. NO_x threshold annual concentration is 40 $\mu g/m^3$ at the year 2010 .

On the basis of actual contaminants emissions, a future potential realistic scenario has been hypothesized, that assumes population increase, traffic increase, renewal of car pool and finally compliance of all stack emissions to predicted threshold limits. The future scenario evidences a decrease in pollutants concentrations levels; as an example figure 1 shows modelled PM_{10} concentration distribution in the actual (a) and future (b) scenario with particular attention to compliance of legal threshold limits.

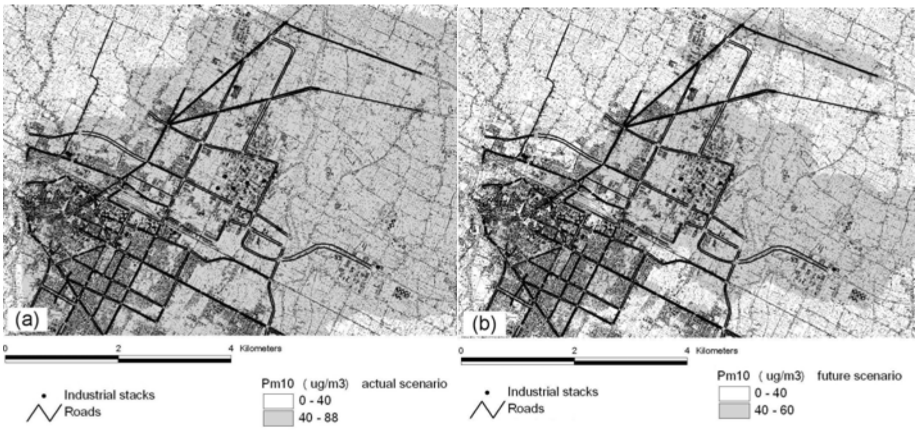

Figure 1. PM_{10} concentration distribution in actual (a) and future (b) scenario.

The aim of the case-study is the quantitative assessment of the human health benefits resulting from the PM_{10} and NO_x concentration decreases. The potential future scenario presents a reduction of both the area in which air contaminants overcomes legal limits and the maximum values of concentrations in the area.

In order to calculate human health benefits, a set of most recent epidemiological data (published in scientific literature) is selected, that better fit to analysed territory. In particular epidemiological studies performed in U.S. and Europe have been analyzed (U.S.EPA, 1999; U.S.EPA, 2003; WHO, 2006). The selected C-R functions for NO_x and PM_{10} pollutants are detailed in Table 1. The considered health endpoints are hospital admissions caused by asthma for NO_x exposure and hospital admissions for Chronic Obstructive Pulmonary Disease (COPD) for PM_{10} exposure.

Table 1. Selection of epidemiological studies (Changes of concentration are in μg/m^3).

Contaminant	HEALTH_ENDPOINT	SOURCE	Y_0 (daily)	β
NO_x	hospital admissions – asthma (European cities)	Touloumi (1997)	$1.808 \cdot 10^{-6}$	$5.78 \cdot 10^{-4}$
PM_{10}	hospital admissions – COPD (Minneapolis, MN)	Moolgavkar et al. (1997)	$3.75 \cdot 10^{-5}$	$8.77 \cdot 10^{-4}$
PM_{10}	hospital admissions – COPD (Minneapolis, MN)	Schwartz (1994)	$3.75 \cdot 10^{-5}$	$4.51 \cdot 10^{-3}$
PM_{10}	hospital admissions – COPD (Birmingham, AL)	Schwartz (1994)	$3.75 \cdot 10^{-5}$	$2.39 \cdot 10^{-3}$
PM_{10}	hospital admissions – COPD (Detroit, MI)	Schwartz (1994)	$3.05 \cdot 10^{-5}$	$2.02 \cdot 10^{-3}$

Four C-R functions are available if COPD decreases are considered, that allows to evaluate the incidence of legislation when different β are considered. Taking into account a decreasing of 20 μg/m^3 in PM_{10} concentrations according to legislation perspective from the year 2005 to 2010, the percentage health benefits in 5 years, per person are reported in Table 2. Differences among studies, which are included in the range 1.74% ÷ 8.63%, are strongly related to the city of the study and probably to other confounders factors.

Table 2. Health benefits consequent to a decrease of 20 μg/m^3 in PM_{10} concentrations.

HEALTH_ENDPOINT	SOURCE	Δy	Δy/y$_0$
hospital admissions – COPD (Minneapolis, MN)	Moolgavkar et al. (1997)	$1.19 \cdot 10^{-3}$	1.74%
hospital admissions – COPD (Minneapolis, MN)	Schwartz (1994)	$5.90 \cdot 10^{-3}$	8.63%
hopital admissions – COPD (Birmingham, AL)	Schwartz (1994)	$3.19 \cdot 10^{-3}$	4.67%
hospital admissions – COPD (Detroit, MI)	Schwartz (1994)	$2.20 \cdot 10^{-3}$	3.96%

In order to apply literature C-R functions to the examined Italian area, the local incidence rates have been searched out in national databases. In particular a value of $9.242 \cdot 10^{-4}$ for annual incidence of hospital admissions for asthma per person and a value of $1.814 \cdot 10^{-3}$ for annual incidence of hospital admission for COPD per person have been derived. Because the expected changes in pollutant concentrations vary from location to location, individuals living in different locations of the area may not experience the same level of health benefits. Taking into account the change in NO_x and PM_{10} concentration between actual and future scenarios, the percentage benefit in health effect is estimated as a distribution in the examined area.

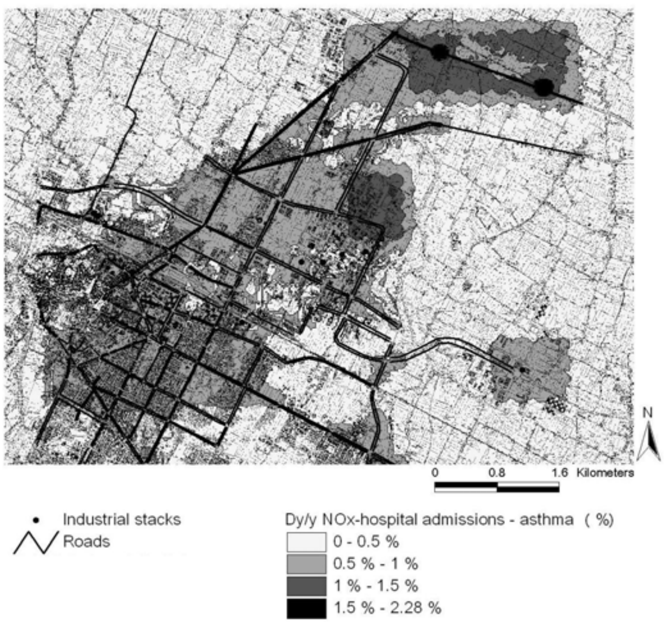

Figure 2. Percentage health benefit Δy/y$_0$ (%) in NO_x hospital admissions for asthma

Figure 2 shows the percentage benefits ($\Delta y/y_0$) in hospital admissions for asthma caused by NO_x decrease from actual to future scenario. The maximum value of benefits in hospital admissions is 2.28% corresponding to a annual Δy of $2.107 \cdot 10^{-5}$ per person; assuming a population of 75000 inhabitants, a decrease of 1-2 cases in annual hospital admissions for asthma is estimated.

PM_{10} health effects benefits are evaluated applying the four selected C-R functions. Figure 3 shows the distribution of benefits in hospital admissions for COPD applying the maximum β coefficient ($\beta = 4.51 \cdot 10^{-3}$). The maximum value of benefits in hospital admissions is 12.26% corresponding to a annual Δy of $2.224 \cdot 10^{-4}$ per person; assuming a population of 75000 inhabitants, a maximum decrease of 16-17 cases in annual hospital admissions for chronic obstructive pulmonary disease is estimated, mainly due to traffic and industrial stacks sources.
Applying the other C-R functions we obtain the following smaller ranges: 2.5% ÷ 6.7% of percentage benefits , $4.53 \cdot 10^{-5} \div 1.215 \cdot 10^{-4}$ of annual Δy per person and 3-4 ÷ 9-10 cases in annual COPD hospital admissions decrease.

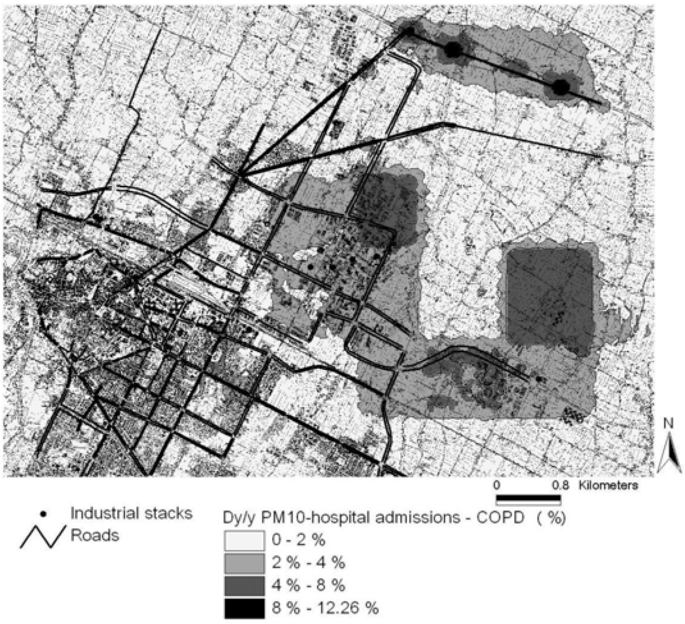

Figure 3. $\Delta y/y_0$ (%) in PM_{10} hospital admissions for COPD

5. Conclusions

The paper deals with the use of C-R functions of air criteria pollutants in establishing quantitative benefits which result from a reduction of air contamination in a territory. After a short discussion about uncertainties included in the functions, a realistic case study is examined, considering diseases due to NO_x and PM_{10}. Processing the available data allows to infer that forecasts on PM_{10} diseases are generally more significant than those due to NO_x exposures. The map also shows that these benefits are located in specific areas of the territory and highlights clearly the influence of the new scenario on human health, if C-R functions are well assessed.

References

D.M. 60/2002 Decreto Ministeriale 2 aprile 2002, n.60. Suppl. n. 77 alla G.U. n. 87 del 13 aprile 2002

D.Lgs. 183/2004 DECRETO LEGISLATIVO 21 maggio 2004, n. 183. Gazz. Uff. 23 luglio 2004, n. 171, S.O.

EC, Commissione delle Comunità Europee. Proposta di Direttiva del Parlamento Europeo e del Consiglio relativa alla qualità dell’aria ambiente e per un’aria più pulita in Europa. 21.9.2005, COM(2005)447

Moolgavkar, S.H., E.G. Luebeck and E.L. Anderson. 1997. Air pollution and hospital admissions for respiratory causes in Minneapolis St. Paul and Birmingham. Epidemiology. 8 (4): 364-370.

Schwartz, J. 1994. PM(10) Ozone, and Hospital Admissions for the elderly in Minneapolis St Paul, Minnesota. Archives of Environmental Health. 49(5): 366-374.

Schwartz, J. 1994. Air pollution and Hospital Admissions for the elderly in Birmingham, Alabama. American Journal of Epidemiology. 139(6): 589-598.

Schwartz, J. 1994. Air pollution and Hospital Admissions for the elderly in Detroit, Michigan. American Journal of Respiratory and Critical Care Medicine. 150(3): 648-655.

Touloumi, G. Short term Effect of Ambient Oxidant exposure on mortality: A combined analysis within the APHEA project Am J Epidemiol 1997; 146:177-185

U.S. Environmental Protection Agency. The Benefits and Costs of the Clean Air Act 1990 to 2010. EPA Report to Congress EPA-410-R-99-001. 1999

U.S. Environmental Protection Agency. Benefits and Costs of the Clean Air Act 1990 – 2020 - Revised Analytical Plan For EPA's Second Prospective Analysis. Office of Policy Analysis and Review. 2003

WHO – World Health Organization, Regional Office for Europe Health aspects of air pollution - results from the WHO project “Systematic review of health aspects of air pollution in Europe” 2004

WHO - Regional Office for Europe, Air Quality Guidelines for Europe - Second Edition, WHO Regional Publications, European Series, No. 91, 2000

WHO – Regional Office for Europe, Air Quality Guidelines. Global Update 2005. 2006

WHO - Regional Office for Europe Effects of air pollution on children’s health and development: a review of the evidence. Copenhagen, 2005.