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Original Research

Effect of Ambient Air Pollution on Daily Mortality in Katowice Conurbation, Poland

M. Kowalska[1]*, L. Hubicki[2], J.E. Zejda[1], L. Ośródka[3], E. Krajny[3], M. Wojtylak[3]

[1]Department of Epidemiology, Medical University of Silesia, ul. Medyków 18, 40-752 Katowice, Poland
[2]Department of Biostatistic, Chair of Public Health, Medical University of Silesia, Katowice, Poland
[3]Institute of Meteorology and Water Management, Katowice, Poland

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Abstract

The impact of air pollution on human health is subject to extensive research. Most evidence concerns the effect of exposure to airborne PM_{10} and $PM_{2.5}$ on daily mortality and hospital admissions. However; less is known about the effects of SO_2.

Our study (time-series analysis) investigates the effects of 24-hour concentrations of PM_{10}, SO_2 and NO_X on daily mortality over 2001-2002 in 14 cities of the Katowice Conurbation.

Results of the study suggest that SO_2 is the major air pollutant affecting the daily mortality profile in Katowice Conurbation. Sulphur dioxide effect is apparent in relation to both general and cardiovascular or respiratory mortality, particularly in the elderly. The effect of PM_{10} concentration is also statistically significant but only to the general mortality pattern.

Keywords: air pollution, mortality, epidemiology, time series analysis

Introduction

Prevention of health disorders related to exposure to air pollution remains an important challenge in many countries and a priority area of international collaboration in environmental health [1-4]. A convenient measure of air pollution-related hazards is the magnitude of association between daily area concentrations of respirable particular matter (PM_{10}), sulfur dioxide (SO_2) or nitric oxide (NO_x) and the number of deaths per day in the exposed population [5-8]. The method not only allows the estimation of the risk but also yields comparable data and provides insight into potential health and socio-economic effects as well as possible benefits resulting from the implementation of preventive measures. A standard way of analysis, based on the time-series approach, has to take into account a number of factors affecting the association in question. Those include such confounders as, for example, chemical composition of air pollution, local meteorological conditions, season of the year, influenza epidemics, or baseline general health status of the exposed population [9-12]. The site-specific factors mentioned above hamper the generalization of the results of risk assessment and it is necessary to obtain population-specific data, characterized by spatial and temporal variation.

Despite the radical air quality improvement in Poland over the last 15 years, increased levels of particulate and gaseous air pollutants are still recorded in this country, mostly because of a dominant method of energy production and heating of houses, based on coal combustion [13]. In some regions this source of exposure is still accompanied by significant exposure from industrial sources. Such a potential for exposure has been a public health concern in the heavily industrialized urban area of Katowice (Katowice Conurbation) composed of 14 cities (Katowice, Bytom, Chorzów, Czeladź, Dąbrowa Górnicza, Gliwice, Mysłowice, Piekary

*Corresponding author; e-mail: kowalska@slam.katowice.pl

Śląskie, Ruda Śląska, Siemianowice Śląskie, Sosnowiec, Świętochłowice, Wojkowice, Zabrze) and inhabited by about 2 million people. Air pollution levels in this region no longer reach the critical values observed some 20-30 years ago but they remain high, especially during the heating season. For example, current monitoring data show that the frequency of days per year with exceeded acceptable 24-hour area concentration of PM_{10} (standard: 50 μg/m^3) ranges from 0.5% to 18.1%, and for SO_2 (standard: 150 μg/m^3) between 0 and 0.3%, depending on the location within the Katowice Conurbation [13].

Relatively high exposures to air pollution and its composition with a dominant role of SO_2 *vis-à-vis* large population justify the assessment of current air pollution-related risk, in terms of mortality. With this caveat in mind we decided to analyze the current relationship between the daily total and specific mortality (cardiovascular and respiratory mortality) and daily PM_{10}, SO_2 and NO_x average area concentrations in the ambient air in the Katowice Conurbation in 2001-2002.

Material and Methods

The principal method of analysis involved regression of daily number of deaths (dependent variable) on average daily area concentration of air pollutants (independent variable), according to time-series scheme.

The number of deaths per day in 2001-2002 in 14 cities of the Katowice Conurbation was obtained from the Central Statistical Office. The records included total number of deaths, the number of deaths without sudden deaths, the number of deaths due to cardiovascular and respiratory diseases for the entire population and in two age categories: less than 65 years, 65 or more years of age. The classification of causes of death was based on the International Classification of Diseases ICD-10 [14]. The category of sudden deaths included deaths with codes R95-R99. The category of deaths due to cardiovascular diseases included deaths with codes I00-I99. The category of deaths due to respiratory diseases included deaths with codes J00–J99.

Data concerning ambient air pollution (temperature, atmospheric pressure and relative humidity) were calculated as 24-hour area averages and as moving averages (three days as the interval). All source data came from automatic measurement stations located in a region, recording concentrations of suspended particular matters with aerodynamic diameter not exceeding 10 micrometers (PM_{10} in μg/m^3), sulfur dioxide (SO_2 in μg/m^3) and nitric acids (NO_x in μg/m^3). Meteorological indices included in analysis were calculated as the daily area averages for air temperature [°C], relative humidity [%] and atmospheric pressure [hPa].

Variability of the daily number of deaths and daily concentrations of pollutants, and metrological parameters was estimated by calculation of the coefficient of variation (CV in%). Statistical significance of differences in the distributions of continuous variables was assessed by means of analysis of variance, and simple associations between the concentration of air pollutants and daily mortality were explored by analysis of correlation, according to Pearson's method.

Analysis of the relationship between daily mortality and daily concentrations of air pollutants (controlled for confounders) was performed using multivariate regression model, including a Poisson's distribution assumption expressed by the logarithmical link function: log[E(ND)=Xβ, where E(ND) is an expected daily number of deaths (dependent variable), X is the matrix of independent variables and β means the calculated regression coefficients.

Association of number of death (Y) with potential explanted variables was examined using GLM procedure, available in the Statistica package. Variables describing ambient air pollutant were expressed as average 24-hours concentration:

(a) on the death day and
(b) on the day preceding death, and
(c) 3-day moving average concentration of each pollutant (PM_{10}, SO_2, NOx).

Due to the correlations between concentrations of pollutants (PM_{10}-SO_2; PM_{10}-NO_x; SO_2-NO_x), the model tested the effect of a single pollutant on a daily number of deaths according to the following formula: Number of Deaths = b0 + b1*Season + b2*Temperature + b3*Humidity + b4*Pressure + b5*Pollutant Concentration. Three specific scenarios were used: impact of concentrations of pollutants recorded on the day of death, on the day preceding a death and pollutions expressed as the moving average in the period preceding the deaths.

The potential effect of the season was controlled by including an independent categorical variable, with two levels. The spring-summer season was contrasted with the fall-winter season. The potential contribution for the effects of temperature, humidity and atmospheric pressure was examined by means of qualitative variables, all expressed in measured units and included in one model. Furthermore, the "single pollutant model" we used allows us to compared the magnitude of examined effects with the published data.

The methods of analysis (model specification, parameterisation and statistical tool) used in our study was the same as the methods applied in a 1994/95 study in order to allow relevant comparison.

The interpretation of the results was based on the criterion of statistical significance of partial regression coefficients ($p<0.05$). All analyses were performed with the use of procedures available in the Statistica 6.0 statistical program.

Results

The total number of deaths in the study period (2001-2002) in the Katowice Conurbation was 39,222, and 14,220 deaths (36%) occurred among people below 65 years of age and 25,002 deaths (64%) among the elderly (age: 65+ years). Nearly all deaths (97%) were due to reasons other than sudden causes.

Cardiovascular diseases were responsible for 31% of deaths in people aged 0-64 years and for 56% deaths in people aged 65+ years. Similarly, deaths due to respiratory diseases in two age categories accounted for 2% and 5% of the entire mortality, respectively. The average daily death count in the analyzed period is shown in Table 1. Day-to-day variability expressed as coefficient of variation is larger for respiratory (CV "0-64": 140%; CV "65+": 82%) than for cardiovascular causes (CV "0-64": 42%; CV "65+": 25%).

Table 2 presents aero-sanitary conditions (daily mean concentrations of air pollution and meteorological conditions) during the study period. The distribution of ambient air pollution also shows a considerable variability (CV) of 24-hour levels (SO_2 – 68%, PM_{10} – 70%, NO_x – 60%), mostly due to high concentrations recorded in the heating season (autumn-winter), in comparison with the spring-summer period. Two seasons differed in terms of the average daily number of deaths and the difference was statistically significant for subset of deaths among people aged 65+ years (Table 3).

Number of deaths per day was associated with the same-day 24-hour concentrations of air pollutants, as shown by the results of analysis of correlation. For all deaths, respective correlation coefficients were statistically significant for all data pertinent to age <65 years (SO_2: r=0.08, p<0.05; PM_{10}: r=0.17, p<0.05; NO_x: r=0.17, p<0.05) and for SO_2 in the case of age 65+ years (SO_2: r=0.27, p<0.05; PM_{10}: r=0.06, p>0.05; NO_x: r=0.06, p>0.05). For all deaths without sudden death causes the respective correlation coefficients were, for age <65 years: 0.08 (p<0.05) for SO_2, 0.06 for PM_{10}, 0.07 (p<0.05) for NO_x, and for age 65+ years: 0.11 (p<0.05) for SO_2, 0.05 (p>0.05) for PM_{10}, 0.05 (p>0.05) for NO_x. Analysis restricted to cardiovascular causes revealed the following correlation coefficients, for age <65 years: 0.08 (p<0.05) for SO_2, 0.02 (p>0.05) for PM_{10}, 0.02 (p>0.05) for NO_x, and for age 65+ years: 0.28 (p<0.05) for SO_2, 0.15 (p<0.05) for PM_{10}, 0.15 (p<0.05) for NO_x. Finally, correlation coefficients in the category of deaths due to respiratory diseases were for age <65 years: 0.08 (p<0.05) for SO_2, 0.07 for PM_{10}, 0.07 for NO_x, and for age 65+ years: 0.17 (p<0.05) for SO_2, 0.11 (p<0.05) for PM_{10}, 0.11 (p<0.05) for NO_x.

The results of multivariate analysis confirmed the effect of air pollution on mortality, controlled for the season, temperature, humidity and atmospheric pressure (Table 4). Modeling included one air pollution related variable at a time because of statistically significant cor-

Table 1. The average daily death count in Katowice Conurbation, in the period 2001-2002.

Cause of death	Age Group	Mean number of deaths/day	Standard deviation	Range (5-95 percentile)
All causes	< 65 years	19.5	4.7	12-28
	65 + years	34.2	6.3	24-45
All deaths without sudden death causes	<65 years	18.4	4.6	11-27
	65 + years	33.7	6.3	24-44
Deaths due to cardiovascular diseases	<65 years	6.0	2.5	2-10
	65 + years	19.3	4.8	12-27
Deaths due to respiratory diseases	<65 years	0.5	0.7	0-2
	65 + years	1.7	1.4	0-4

Table 2. Daily mean concentrations of ambient air pollution and meteorological conditions in Katowice Conurbation, in the period 2001-2002.

Parameter	Mean	Standard deviation	Range (5-95 percentile)
Sulfur dioxide SO_2 [μg/m^3]	35.2	24.2	13.9-80.8
Particulate matter PM_{10} [μg/m^3]	49.0	34.3	18.4-104.6
Nitrogen oxides NOx [μg/m^3]	49.8	29.8	21.8-111.4
Temperature [°C]	8.9	8.4	-5.1-21.0
Humidity [%]	78.6	10.8	58.8-94.2
Atmospheric pressure [hPa]	982.6	7.9	969.8-996.6

relations between all three variables in question. Table 4 shows specific results, by age group, and for three defined modes of exposure ("same-day concentration," "previous-day concentration," "moving three-day concentration"). The findings reveal the impact of air pollution on mortality except for the category of respiratory causes of death, probably due to the small number of observations in that category. The strongest effect is seen for SO_2 exposure while the effects of NO_x and PM_{10} are smaller and similar in magnitude. An interesting observation is that

Table 3. Average daily number of deaths in two seasons, autumn-winter and spring-summer, in the period 2001-2002 in Katowice Conurbation.

Cause of death	Age Group	Autumn-Winter* SO_2: 61.6±31.8 PM_{10}: 70.4±52.9 NO_x: 68.3±38.5	Spring-Summer* SO_2: 19.0±5.1 PM_{10}: 35.3±15.2 NO_x: 32.8±10.5	P**
All causes	< 65 years	20.0 ± 4.5	18.8 ± 4.7	0.01
	65 + years	37.8 ± 5.7	31.8 ± 5.6	<0.0001
All deaths without sudden death causes	<65 years	18.8 ± 4.4	17.8 ± 4.5	0.04
	65 + years	37.1 ± 5.7	31.3 ± 5.6	<0.0001
Deaths due to cardiovascular diseases	<65 years	6.3 ± 2.5	5.6 ± 2.5	0.01
	65 + years	21.9 ± 4.9	17.7 ± 4.3	<0.0001
Deaths due to respiratory diseases	<65 years	0.6 ± 0.8	0.4 ± 0.7	0.01
	65 + years	2.2 ± 1.5	1.3 ± 1.2	<0.0001

Legend: *mean 24-hour concentration of air pollutants [in μg/m^3]; ** p – statistical significance of the between-season difference

Table 4. Effect of air pollution level on daily mortality, by cause of death and age group in Katowice Conurbation, in 2001-2002 (the table shows regression coefficients of the analyzed pollutants, controlled for season effect, daily temperature, humidity and atmospheric pressure).

Pollutant	Format of the independent variable	Coefficient of regression							
		All causes		All causes without sudden deaths		Cardiovascular deaths		Respiratory Deaths	
		Age: <65	Age: 65+	Age: <65	Age: 65+	Age: <65	Age: 65+	Age: <65	Age: 65+
NO_x	Concentration on the death day	0.0056	0.0087	0.0041	0.0089	-0.0038	0.0046	0.0005	0.0016
	Concentration on the day preceding death	0.0168*	0.0142	0.0154*	0.0143	0.0026	0.0052	-0.0006	0.0019
	3-day moving average concentration, preceding death	0.0146	0.0254*	0.0121	0.0251*	-0.0005	0.0127	-0.0002	0.0032
PM_{10}	Concentration on the death day	0.0060	0.0097	0.0051	0.0098	-0.0025	0.0058	0.0008	0.0021
	Concentration on the day preceding death	0.0133*	0.0167*	0.0118*	0.0170*	0.0026	0.0137*	-0.0003	0.0031
	3-day moving average concentration, preceding death	0.0127	0.0238*	0.0109	0.0236*	0.0011	0.0182*	0.0007	0.0038
SO_2	Concentration on the death day	0.0163	0.0208	0.0150	0.0201	-0.0003	0.0204	0.0018	0.0049
	Concentration on the day preceding death	0.0273*	0.0398*	0.0250*	0.0383*	0.0076	0.0334*	0.0009	0.0052
	3-day moving average concentration, preceding death	0.0267*	0.0446*	0.0245*	0.0425*	0.0046	0.0393*	0.0020	0.0064

Legend: * – coefficient statistically significant (p<0.05) the variables expressing accumulated exposure explain the examined association in better way than the variables reflecting same-day environmental conditions.

Discussion of Results

The results of our study suggest that the currently measured concentrations of airborne particulate and gaseous pollutants in the Katowice Conurbation influence the daily mortality pattern among the inhabitants of the region. The largest impact is seen in relation to the elderly and in the case of cardiovascular mortality. Sulfur dioxide remains the most powerful determinant among the examined air pollutants. This finding is similar to the earlier observation in the same region, obtained in 1994-1995 [15].

Association of daily mortality with exposure to ambient air pollution, also seen in our study, provides scientific grounds for preventive measures [2-4]. However, two issues deserve attention. The first one concerns a question of environmental standards that are difficult to define because of a linear association between exposure level (concentration) and mortality, with no apparent cutoff value [16]. Both aspects justify continuation of epidemiological risk assessment, under different exposure scenarios. From that point of view the results of our study might contribute to the process of standards setting in the field of air quality and their periodical review, also using epidemiological approach as recommended by the World Health Organization [17-18].

The second important issue is a relative contribution of different air pollutants, where particulate matter is considered the most important factor. A systematic review of air pollution – mortality studies in the USA and in the countries of Western Europe has shown a consistently stronger effect of PM_{10} compared to SO_2, unlike in our study [19]. It is difficult to explain that difference. It could be speculated that the principal role of SO_2 in our study results from that pollutant's concentrations, much higher in the Katowice Conurbation than in environmental settings included in the review quoted above. Moreover, the "SO_2 effect" in the region was also found for other health outcomes, such as incidence of respiratory diseases in children or changes in lung function [20-22]. A consistency of the "SO_2 effect" cannot be neglected and seems to support the argument concerning the reliability of our study results [23]. A similar, stronger relation between the concentration of sulfur dioxide and daily mortality compared to other air pollutants was also found in Kraków. The Kraków study confirmed a vulnerability of the elderly and proved the effect of preceding exposure, covering a three-day period prior to death [9]. Earlier evidence from the APHEA project conducted in Poland revealed significant region-to-region differences, with statistically significant relationships for cardiovascular deaths and air pollution only seen for SO_2 concentrations in Kraków [24].

It cannot be ruled out that a relatively low impact of airborne particulate matter in Polish studies is related to a specific composition of ambient air pollution resulting, in particular, from the combustion of coal and its products to obtain energy [25-26]. A similar exposure scenario (coal as a principal source of energy) takes place in some regions of China, where SO_2 concentrations were found to better correlate with daily mortality than did PM_{10} levels [27]. Another, independent observation of the statistically significant influence of SO_2 on mortality pattern was provided by a study performed in Athens [29].

Seasonality of the mortality profile is well documented and the effect is explained by the influence of low temperatures [28, 30-32]. It is not possible to extract such influence in the conditions characteristic for the Katowice Conurbation because low temperatures (heating season) are accompanied by large concentrations of particulate and gaseous air pollutants. Other factors, controlled in our study, also correlate with ambient air pollution levels. Nevertheless, the causative effect of exposure to pollutants cannot be questioned. Both accumulated body of evidence and biological plausibility are obvious with respect to the risk. Indirect support is provided by an apparent age-dependent gradient in pollution-related mortality risk. Moreover, an interesting finding is that mortality outcome on a given day is more sensitive to a cumulative than concurrent exposure, the feature that can also be discussed in terms of the burden of recent exposure. Nevertheless, a more specific interpretation regarding biological mechanisms of the examined association is impossible because of the limitation of time-series analysis, including an imperfect accuracy of death certificates, unknown health status of the deceased and above all an ecological design of this type of a study.

In conclusion, airborne sulphur dioxide is the principal air pollutant affecting daily mortality profile in Katowice Conurbation. Exposure to SO_2 is apparent in relation to both general and cardiovascular or respiratory mortality, particularly in the elderly. The effect of exposure to PM_{10} is smaller but statistically significant in relation to the general mortality pattern.

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