Original Research

Short-Term Effects of Ambient Air Pollution on Daily Mortality

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Abstract

In environmental epidemiology, short-term effects of ambient air pollution on mortality are explored using time-series analysis including various definitions of the exposure variable. In order to find out if and to what extent the magnitude of air pollution-related relative risk of death depends on the definition of the exposure variable, we analyzed data on daily mortality and air pollution concentrations obtained in the city of Katowice in 2001-02 (range of daily number of deaths: 17-76; range of 24-hour concentrations in μg/m^3: PM_{10} = 11.2-421.3, SO_2 = 10.5-239.8, NO_x = 15.7-287.7). The modeling results confirmed the dominant role of SO_2 among the monitored ambient air pollutants, after adjustment for meteorological variables. The value of SO_2-related relative risk of death (total mortality) depended on the definition of exposure variable – for same-day concentrations of SO_2 it was 1.007, and for a three-day moving average it was 1.012. The largest values of risk estimates were provided by exposure variables expressed as a 40-day moving average (SO_2-related relative risk = 1.022). Our findings highlight the importance of the choice of the model (including definition of exposure variables) in exploring time-series mortality data. On biological grounds our findings suggest that people at risk of death (i.e. elderly with cardiorespiratory disorders) could be more affected by an accumulating burden of exposure (expressed by average air pollution levels over a longer period) than by acute exposures to increasing air pollution levels.

Keywords: ambient air pollution, PM_{10}, SO_2, daily mortality, Katowice, Poland

Introduction

The impact of ambient air pollution on mortality has been documented by numerous studies [1-6]. However, the magnitude of the effect depends on a number of factors. Putting aside the factors related to between-population and/or between-exposure differences, it is of interest to investigate the effects of point versus cumulative exposures estimated for one study location. Moreover, from a biological perspective it is intriguing that some findings suggest a long persistence of the effect, reaching even 30 days [7-10]. Most studies have addressed the risk related to ambient air concentrations of particulate matter (PM_{10}); the best evidence concerning a differential role of the definition of exposure is pertinent to that air pollutant. In the Katowice area (Poland) the level of sulphur dioxide (SO_2) in the ambient air appears to be the most important determinant for daily total and cardiopulmonary mortality [11]. We decided to find out if and to what extent the SO_2-related effect depends on the mode of exposure. In particular, using a time-series analysis we compared the magnitudes of the mortality impacts of SO_2 levels, expressed by moving average concentrations calculated for a various number of days prior to the mortality index day.

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Table 1. Daily number of all deaths, deaths due to cardiorespiratory causes, and 24-hour air quality measures (ambient air concentrations of PM_{10}, NO_x and SO_2, and meteorological variables) for Katowice in the period 2001-02.

Parameter	Mean value	SD	Minimum value	10th percentile	50th percentile	95th percentile	Maximum Value
Daily number of deaths in total population	52.7	8.8	15	42	52	68	76
Daily number of deaths in population aged 65 and more	33.4	6.2	11	25	33	44	51
Deaths due to cardiorespiratory diseases in total population	26.8	5.9	6	19	27	37	41
Deaths due to cardiorespiratory diseases in population aged 65 and more	20.3	4.9	5	14	20	29	34
SO_2 [μg/m³]	35.2	24.2	10.5	15.9	27.1	80.8	239.8
NO_x [μg/m³]	49.8	29.8	15.7	24.4	40.8	111.4	287.7
PM_{10} [μg/m³]	49.0	34.3	11.2	21.5	39.5	104.6	421.3
Temperature [ºC]	8.9	8.4	-17.2	-2.1	9.4	21.0	26.1
Relative Humidity [%]	78.6	10.9	43.8	63.9	80.3	94.2	97.9
Atmospheric Pressure [hPa]	982.6	7.9	960.5	972.9	982.2	996.6	1,008.5

Experimental Procedure

Our study concerns the city of Katowice, which constitutes a large industrial region known for a long history of extensive coal mining, steel and chemical production. The Katowice area is located in the central part of Silesia Voivodeship (administrative district in Poland), inhabited by about 2 million people. At the time of analysis the annual number of deaths recorded in the Katowice agglomeration was approximately 20,000; half of them were caused by circulatory diseases and only 4% of the total mortality was due to respiratory diseases. Analysis for the daily mortality and the daily moving average concentrations of gaseous or particulate air pollution was performed using the multivariate Poisson regression model, according to the formula:

$$\text{DEATHS} = b_0 + b_1\text{*SEASON} + b_2\text{*TEMPERATURE} + b_3\text{*HUMIDITY} + b_4\text{*ATMOSPHERIC PRESSURE} + b_5\text{*POLLUTANT CONCENTRATION}$$

Daily numbers of deaths for the area were obtained from the Central Statistical Office in Warsaw and the records included the total number of deaths (excluding sudden deaths, according to ICD-10 codes R95-R99) and deaths due to circulatory and respiratory diseases (according to ICD-10 codes: I00-I99 and J00-J99). The classification of causes of mortality is based on the International Classification of Diseases ICD-10 (International Statistical Classification of Diseases and Related Health Problems, 10th revision. Version for 2007. Available at www.who.int).

Data on ambient air pollution was provided by the State Environmental Agency in Katowice. For each day the 24-hour spatial average concentrations of PM_{10}, SO_2 and NO_x were calculated as the average of all 11 site-specific measurements, monitored in the Katowice area. The exposure variables were expressed as either mortality-index day concentrations of SO_2 or NO_x and PM_{10} or separate moving averages calculated for 3, 5, 7, 14, 30, 40, 50 and 60 days, subsequently.

The relative risk (RR) estimates of the total and circulatory/respiratory deaths in relation to a 10 μg/m³ increase in SO_2, NO_x and PM_{10} were calculated using the formula:

$$RR = e^{\text{b delta}}$$

...where b is the regression coefficient of the pollutant in question and delta is its increase by 10 μg/m³.

Some meteorological parameters were included in the analysis expressed as daily area average measurements of air temperature [ºC], relative humidity [%] and atmospheric pressure [hPa]. In addition, the potential effect of seasons was controlled by including an independent categorical variable (values: 1, 2, 3, 4 for winter, spring, fall and summer, respectively). According to the official reports by the National Institute of Public Health in Poland, during the study period there were no influenza epidemics (National Institute of Public Health. Infectious diseases and poisonings in Poland annual report. Available at www.pzh.gov.pl).

The analyses were performed for the total number of deaths and – separately – for the deaths occurring at the age of 65 or more [10]. Moreover, separate analyses involved all-cause deaths and cardiorespiratory deaths as dependent variables. All analyses were performed using procedures available in the SAS statistical package (SAS/STAT Guide for Personal Computers, Version 9.1. SAS Institute Inc.,

Table 2. Values of the regression coefficients and their 95% confidence limits (in brackets) obtained from a multivariate analysis with each air pollutant as independent variable, expressed in a number of ways, from same-day concentration to 60-day moving average concentration, in the total daily mortality of the general population.

Air pollutant	Day of death	3-day moving concentration	5-day moving concentration	7-day moving concentration	14-day moving concentration	30-day moving concentration	40-day moving concentration	50-day moving concentration	60-day moving concentration
SO_2	0.0007	0.0012	0.0013	0.0014	0.0016	0.0020	0.0022	0.0019	0.0015
	(0.0001 0.0012)	(0.0005 0.0019)	(0.0005 0.0020)	(0.0005 0.0022)	(0.0005 0.0026)	(0.0006 0.0034)	(0.0006 0.0037)	(0.0004 0.0035)	(0.0001 0.0030)
PM_{10}	0.0003	0.0007	0.0007	0.0008	0.0004	0.0013	0.0014	0.0013	0.0011
	(0.0000 0.0006)	(0.0003 0.0011)	(0.0002 0.0011)	(0.0003 0.0014)	(0.0002 0.0018)	(0.0000 0.0026)	(0.0000 0.0028)	(-0.0002 0.0027)	(-0.0004 0.0026)
NO_x	0.0003	0.0007	0.0008	0.0011	0.0013	0.0015	0.0012	0.0008	0.0007
	(-0.0001 0.0006)	(0.0003 0.0012)	(0.0003 0.0014)	(0.0005 0.0018)	(0.0004 0.0022)	(0.0003 0.0028)	(-0.0001 0.0025)	(-0.0005 0.0022)	(-0.0007 0.0021)

Cary, NC. 2001). The interpretation of the results was based on the criterion of the statistical significance of $p<0.05$.

Results

The daily number of deaths recorded in the Katowice area in the period 2000-01 ranged between 17 and 76, and the daily number of deaths due to circulatory or respiratory causes between 6 and 41 (Table 1). Table 1 also shows the mortality according to the defined age categories, as well as the distributions of ambient air quality and meteorological parameters.

Table 2 presents the values of the regression coefficients and their 95% confidence intervals obtained from the multivariate analysis with each selected air pollutant as independent variable, expressed in a number of ways, from same-day concentration to 60-day moving average concentration. The results are shown for deaths recorded in all ages and for all causes. Regression coefficients reveal the largest value for SO_2, and increase with the increase of time frame used to calculate moving average concentration of SO_2.

Figs. 1-4 show estimated risk of death related to a 10 μg/m^3 increases in PM_{10}, SO_2 and NO_x, according to the increasing number of days used to calculate the moving average concentrations. (Fig. 1: all deaths, all age categories; Fig. 2: circulatory and respiratory deaths, all age categories; Fig. 3: all deaths, age 65+; Fig. 4: circulatory and respiratory deaths, age 65+). The risk for all and specific causes, for all ages and for 65+ obtained the largest values in the models for the 30-day and 40-day moving averages.

Discussion

The results of our study confirmed the dominant role of SO_2 and not of PM_{10} among ambient air pollutants that are associated with daily mortality in Katowice. This finding is consistent with the profile of ambient air pollution in the region [WHO HFA-DB. European health for all database. WHO, updated 2006. Available at www.who.int,12]. The effect of SO_2 has also been documented in other time-series analyses, involving observations obtained under similar environmental conditions [10, 13, 14]. Although Pope and

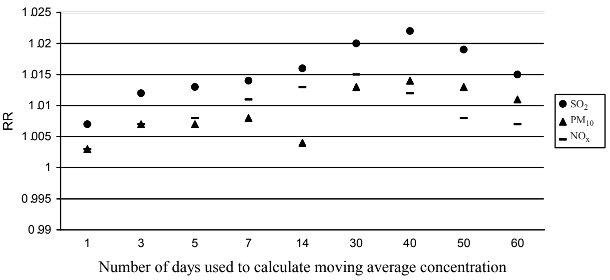

Fig. 1. Relative risk (RR) of total mortality related to an increase of PM_{10}, SO_2 and NO_x concentration by 10 μg/m^3, according to different calculations of the moving average concentrations – all deaths, all age categories in Katowice for the period 2001-02.

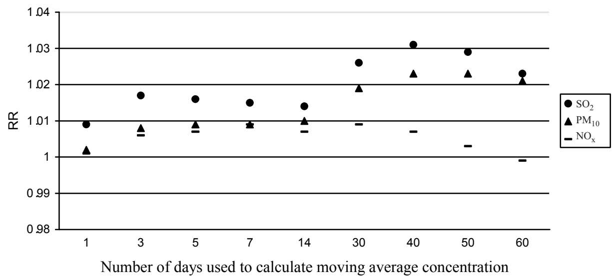

Fig. 2. Relative risk (RR) of total mortality related to an increase of PM_{10}, SO_2 and NO_x concentration by 10 μg/m^3, according to different calculations of the moving average concentrations – cardiorespiratory deaths, all age categories in Katowice for the period 2001-02.

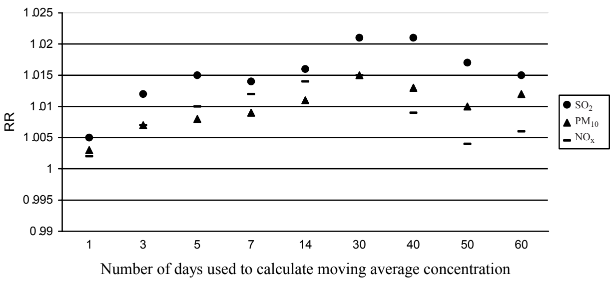

Fig. 3. Relative risk (RR) of total mortality related to an increase of PM_{10}, SO_2 and NO_x concentration by 10 µg/m³, according to different calculations of the moving average concentrations – all deaths, age 65+ years in Katowice for the period 2001-02.

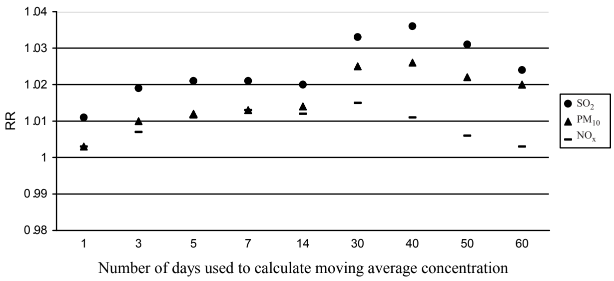

Fig. 4. Relative risk (RR) of total mortality related to an increase of PM_{10}, SO_2 and NO_x concentration by 10 µg/m³, according to different calculations of the moving average concentrations – cardiorespiratory deaths, age 65+ years in Katowice for the period 2001-02.

Dockery [10] suggest that SO_2 may have functioned better as a surrogate for $PM_{2.5}$, our findings provided by the analysis of mortality in association with fine particle ($PM_{2.5}$) obtained in another large city of the study region (Zabrze) didn't confirm such a view. Our recently obtained (unpublished) results did not show the role of fine particles in daily mortality; moreover, the correlation between $PM_{2.5}$ and SO_2 in Zabrze was not very strong (r=0.55). On the other hand, the correlation of NO_x with $PM_{2.5}$ in Zabrze was higher (r=0.88); these results are similar to the findings of Lewne data [15]. Moreover, the values of relative risk of death for levels of NO_x ("a surrogate" for $PM_{2.5}$ in Zabrze) were lower compared to the effect of SO_2 (Figs. 1-4).

The most important finding of our study concerns the role of handling the exposure variable in the time-series analysis on air pollution-related mortality. The largest risk for both total and cardiorespiratory deaths was provided by the models involving a 30-40-day moving average concentration of all measured pollutants: SO_2, NO_x and PM_{10}. Similar conclusions come from studies performed by other authors [9, 16]. The effect, known as "mortality displacement", could be discussed in terms of a cumulative contribution of long-term exposures to the mortality risk, only partially captured by time-series analyses [7, 10]. The models based on same-day reports of mortality and air pollution or models involving short lag periods are likely to underestimate the cumulative effect of ambient air pollution on mortality [17]. Recent data show that a link between air pollution and mortality can be shown by time-series approach even at relatively low levels of air pollutants; however its presence is better documented if the association is explored at a longer time scale, i.e. 14, 30 or even 40 days [8, 9, 18]. In our study the risk estimated by the analysis involving a 40-day moving average concentration was twice as big as the one resulting from a 3-day moving average concentration in the model (for SO_2 related total mortality 3.7% and 1.9%, respectively; for PM_{10} related total mortality 2.6% and 1.0%, respectively; and for NO_x related total mortality 2.5% and 1.2%, respectively). The magnitude of the difference justifies caution as far as the choice of the model to assess the relative risk of death outcomes is concerned [19, 20].

In conclusion, the results of the time-series analysis on air pollution-related mortality depend on the mode of expressing the implicated variables. The moving average concentration of an air pollutant seems to be a useful measure of exposure, not only because of its ability to reflect cumulative exposure but also in biological terms. The largest effect provided by a 30-40 day moving average concentration could be in line with the concept of the harmful effects of prolonged, cumulative, exposure to increased ambient air pollution over longer periods. Such an effect could reflect a concept that individuals at risk (susceptibility due to advanced age and/or chronic cardiorespiratory disorders) could be more sensitive to a biologically pertinent burden of prolonged exposure than to short-term acute increases of exposure.

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