Original Research

Air Pollution and Daily Mortality in Urban Katowice, 1994-95 and 2001-02

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Abstract

A permanent improvement in ambient air quality in the Urban Area of Katowice over recent years could have resulted in a decreased risk of air pollution-related daily mortality. Our study investigates the risk associated with the levels of PM_{10} and SO_2, obtained seven years apart (time-series analyses in 1994-95 and 2001-02). For both periods the acute mortality risk depends more on SO_2 than on PM10 levels. The permanent improvement in ambient air pollution was associated with a decrease in relative risk of mortality, only for SO_2 levels. For example, the magnitude of the total mortality relative risk related to a 10 $\mu g/m^3$ increase in pollutant's concentration (a 3-day moving average) was for SO_2 1.019 (1.015-1.023) in 1994-95 and 1.012 (1.005-1.019) in 2001-02, and for PM_{10} 1.007 (1.004-1.011) in 1994-95 and 1.007 (1.003-1.011) in 2001-02.

Keywords: daily mortality, PM_{10}, SO_2, epidemiology, time series analysis

Introduction

A large number of studies have reported an increased risk of mortality associated with acute ambient air pollution exposure. A rough search of PubMed yields 1098 papers identified by search the term 'air pollution mortality,' published in the last 10 years. The magnitude of the acute impact of particulate and gaseous ambient air pollution on daily total and specific mortality has been used to promote preventive measures in the field of public health [1-5]. A pertinent lesson coming from the dramatic consequences of smog episodes in the 20th century was followed by a convincing observation of a decreased mortality in response to the decrease of air pollution during a steel mil shut down in the Utah valley (U.S.A.) in 1987 [6]. Today, when air pollution levels are much lower than they had been in the past, a justification for public health intervention is based on extrapolation of the results of time-series analyzes. However, only a few studies reported on the changes in mortality in relation to a permanent, significant decrease in air pollution [7, 8].

In Poland, after the political and economical change in 1990 the quality of environment became one of the national target priorities, and the effort towards environmental clean-up has resulted in a substantial improvement of ambient air quality [9]. The largest effect was seen in the urban area of Katowice (Poland), known for high levels of industry-related air pollution. A time-series analysis performed in 1994-5 revealed the most significant effect of exposure to sulphur dioxide (SO_2), followed by particulate matter (PM_{10}) [10]. Since then the quality of ambient air has significantly improved. Between 1994 and 2002 ambient air daily average concentrations of pollutants have decreased by 38% in the case of SO_2 and by 14% in the case of PM_{10}.

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Table 1. Total and average daily count of deaths in the Urban Area of Katowice in 1994-95 and 2001-01.

Cause of death	Period (years)	Total number of deaths in the study period	Mean value (deaths/day)
Total deaths	1994-95	40,691	55.7
	2001-02	39,222	53.7
Deaths due to cardiovascular diseases	1994-95	16,864	23.1
	2001-02	18,456	25.3
Deaths due to respiratory diseases	1994-95	1,604	2.2
	2001-02	1,594	2.2
Total deaths in population aged 65 years or more	1994-95	17,730	24.0
	2001-02	25,002	34.2

Table 2. Daily mean concentrations of ambient air pollution (SO_2 and PM_{10}) in the Urban Area of Katowice, in 1994-95 and 2001-02.

Period (years)	Pollution	Distribution of daily concentrations ($\mu g/m^3$)			Distribution of daily values according to percentiles				
		Mean value	Minimum value	Maximum value	25%	50%	75%	90%	95%
1994-95	SO_2	57	9	315	29	46	73	107	138
	PM_{10}	57	11	324	34	47	67	102	134
2001-02	SO_2	35	10	240	20	27	43	64	81
	PM_{10}	49	11	421	28	39	60	86	105

The apparent decline in ambient air pollution created an opportunity to find out if the pattern of acute (day-to-day) mortality has responded to the decreased exposure, under 'natural experiment' scenario. With this caveat in mind we decided to repeat a 1994-95 assessment 7 years later. The aim of our study was to compare the estimated effect of ambient air pollution on mortality, obtained by the same method 7 years apart (1994-95 - 2001-02) in a large population of the urban area of Katowice. A supporting impetus to our study stemmed from our interest in the role of sulphur dioxide among potential correlates of acute mortality. In a comprehensive review of health effects of air pollution, sulphur dioxide was not named among 'pollutants of current interest' and the reason was that its concentration 'has decreased strikingly' [1]. The diagnosis is fair and sound for many – mostly privileged – but not for all countries.

Experimental Procedures

The urban area of Katowice is a densely populated industrial region (coal mining, steel and chemical industries). It is composed of fourteen adjacent towns (2 million inhabitants). In 1993 the State Environmental Agency installed in the region a network of 11 air quality monitors, providing on-line measurements of such air pollutants as SO_2 and PM_{10}. The results of measurements are being collected, analyzed and published by the Institute of Meteorology, located in Katowice. For two major air pollutants (SO_2, PM_{10}) the 24-hour area average concentrations (daily mean concentrations) were calculated as the average of all site-specific measurements and those data were used in a time-series analyses, covering two calendar years 1994-95 and two calendar years 2001-02.

Mortality data were obtained from the registry at the Central Statistical Office in Warsaw. The records were analyzed according to the classification scheme of the International Classification of Diseases – 9th Edition (ICD-9) and included in the data base if the place of residence of a deceased person was within the administrative boundaries of the urban area of Katowice. Daily counts of nontrauma deaths were arranged in three categories: all deaths (ICD-9 codes <800), deaths due to cardiovascular causes (ICD-9 codes: 390-448) and deaths due to respiratory causes (ICD-9 codes: 460-496). Altogether the number of daily mortality reports was similar in both compared periods: 1994-95 and 2001-02, and included 730 reports from January 01 to December 31 for each period.

For each study day the Institute of Meteorology provided additional data, such as daily mean temperature (TEMP in degrees centigrade – C°), daily mean relative humidity (HUM in %) and daily mean atmospheric pressure (PRES in hPa). The data set included also a four-level variable describing a climatic season (SEAS: 'winter,' 'spring,' 'summer' and 'fall').

Table 3. Associations of daily count of total deaths or deaths due to cardiorespiratory diseases with mean daily concentrations of SO_2 and PM_{10} (adjusted for temperature, relative humidity, atmospheric pressure and season) in the urban area of Katowice, 1994-95 and 2001-02.[a]

Independent variable		Total deaths		Cardiorespiratory mortality	
		Years 1994-95	Years 2001-02	Years 1994-95	Years 2001-02
SO_2 level (μg/m³)	day of death	0.0014	0.0007	0.0017	0.0009
		(0.0001-0.0017)	(0.0001-0.0012)	(0.0009-0.0025)	(0.0001-0.0017)
	3-day moving concentration	0.0019	0.0012	0.0026	0.0017
		(0.0015-0.0023)	(0.0005-0.0019)	(0.0006-0.0047)	(0.0008-0.0026)
PM_{10} level (μg/m³)	day of death	0.0006	0.0003	0.0007	0.0002
		(0.0003-0.0009)	(0.0000-0.0006)	(0.0004-0.0011)	(-0.0002-0.0007)
	3-day moving concentration	0.0007	0.0007	0.0013	0.0008
		(0.0004-0.0011)	(0.0003-0.0011)	(0.0005-0.0020)	(0.0003-0.0014)

[a] The table shows the values of regression coefficients and their 95% CI in the brackets.

Table 4. The relative risk of death related to a 10 μg/m³ increase in the concentration of air pollutants in population aged 65 and more, in the urban area of Katowice, 1994-95 and 2001-02.

Independent variable		RR of death related to 10mg/m³ increase of concentration			
		Total deaths		Cardio-respiratory mortality	
		1994-95	2001-02	1994-95	2001-02
SO_2 level (μg/m³)	24-hour concentration	1.6%	0.5%	1.7%	1.0%
	3-day moving concentration	2.3%	1.2%	2.4%	1.9%
PM_{10} level (μg/m³)	24-hour concentration	0.7%	0.3%	0.7%	0.3%
	3-day moving concentration	0.9%	0.7%	1.0%	1.0%

Raw association of daily number of deaths with daily levels of air pollution was examined by analysis of simple correlation. In order to control for autocorrelation and confounders (TEMP, HUM, PRES, SEAS) a multivariate Poisson regression model was used [11]:

$$\mathrm{DEATHS} = b_0 + b_1{*}\mathrm{SEAS} + b_2{*}\mathrm{TEMP} + b_3{*}\mathrm{HUM} + \\ + b_4{*}\mathrm{PRES} + b_5{*}\mathrm{POLLUTANT}$$

Due to between-pollutants correlation only one pollutant (either SO_2 or PM_{10}) was used in the model. The relative risk of daily mortality related to the increase of air pollution concentration by 10μg/m³ was calculated using the formula: Relative Risk (RR) = $e^{b_5 \mathrm{delta}}$, where b_5 is the regression coefficient of the pollutant and delta is the fixed increase range of concentration (here: 10μg/m³). Additionally, a percentage change in mortality was calculated as the (RR-1) times 100%.

Multivariate analyzes were performed for two dependent variables (all deaths and cardiovascular/respiratory deaths) based on the total population and its segment 65+ years of age. Moreover, the pollutant on the event day was expressed as the mean area concentration or 3-day moving average concentration. Interpretation of statistical significance of the results was based on the criterion $p<0.05$. SAS statistical software was used for all of the calculations (SAS Inc, Cary, NC, USA).

Results

In both compared periods (years 1994-95 and 2001-02) the recorded total number of all deaths, cardiovascular and respiratory deaths were similar (Table 1). However, the burden of mortality has shifted from a younger to an older segment of the population, in line with the demographic transition in Poland. Deaths from cardiovascular causes accounted for approximately 50% of mortality on both occasions, and the percentage of respiratory mortality remained virtually unchanged (3.9% and 4.0%, respectively). Over the period 1994-95-2001-02 the mean daily concentrations of SO_2 and PM_{10} in the urban area of Katowice have substantially declined (Table 2). The concentrations of SO_2 have decreased by 38% and of PM_{10} by 14%.

The correlation analysis revealed association between daily mortality and daily air pollution, both in 1994-95 and 2001-02. The values of correlation coefficients were similar in both periods, for example in relation to the total population (age: 0+ years):

total number of deaths from SO_2: r = 0.26 in 1994-95 and r = 0.30 in 2001-02;

total number of deaths from PM_{10}: r = 0.16 in 1994-95 and r = 0.17 in 2001-02;

respiratory/cardiovascular deaths from SO_2: r = 0.30 in 1994-95 and r = 0.28 in 2001-02;

respiratory/cardiovascular deaths from PM_{10}: r = 0.16 in 1994-95 and r = 0.17 in 2001-02.

Similar results were found in relation to the subpopulation aged 65+ years.

The results of multivariate analyzes confirmed the relationship between daily count of deaths and mean daily concentrations of SO_2 and PM_{10}. After adjusting for variables expressing meteorological conditions and seasons, the effects of SO_2 and PM_{10} remained statistically significant explanatory variables for variation in total mortality (as tested in separate models for SO_2 ad PM_{10}) as shown in Table 3. The statistical effect of SO_2 and PM_{10} were larger when daily concentrations of the pollutants were replaced by their respective 3-day moving average concentrations, the b5 value of SO_2 changed from 0.0014 (24-hour concentration) to 0.0019 (3-day moving average concentration) in 1994-95 and from 0.0007 (24-hour concentration) to 0.0012 (3-day moving average concentration) in 2001-02; the b_5 value of PM_{10} changed from 0.0006 (24-hour concentration) to 0.0007 (3-day moving average concentration) in 1994-95 and from 0.0003 (24-hour concentration) to 0.0007 (3-day moving average concentration) in 2001/2. A similar effect was documented for cardiorespiratory mortality with the following regression coefficients (Table 3).

The magnitude of the relative risk (RR) related to a 10 $\mu g/m^3$ increase in the concentration of air pollutants was calculated for the results obtained in the age category 65 + years. The findings suggest that as compared to the years 1994-95 the risk related to SO_2 concentrations becomes apparently lower in 2001-02, whereas in the case of PM_{10} its reduction is much smaller (with respect to 24-hour concentration and a 3-day moving average concentration), the obtained results are presented in Table 4.

Discussion

Our study resulted in two interesting findings. The most important finding is that the permanent decrease in daily concentrations of ambient air pollution is associated with a decrease in a relative risk of mortality, and that the effect is differential, stronger for the pollutant showing larger decrease. The second interesting finding is that the acute mortality risk in relation to daily exposures to ambient air pollution depends more on SO_2 levels than on PM_{10} levels.

There are not too many studies demonstrating a benefit of the reduction in air pollution, in terms of general and specific mortality. The Dublin intervention study showed that improvement in air quality led to an immediate reduction in cardiovascular and respiratory deaths [8]. The Hong Kong intervention study showed that an isolated drop in SO_2 concentrations was associated with a mortality reduction, both general and due to cardiovascular and respiratory causes, especially in the elderly [7]. Our findings are in line with the published figures [7, 8]. For total death count risk related to SO_2 concentration decreased from 2.3% in 1994-95 to 1.2% in 2001-02 and in the case of PM_{10} from 0.9% to 0.7%, respectively. The largest estimates were provided by a moving average concentration in a model, thus confirming a well known finding that a moving average of air pollution levels better describes the association between exposure and mortality than does a single day's measurement [12]. We saw this effect for both examined pollutants.

Unlike with the interest in PM–related effects, the impact of SO_2 has been elaborated only in some studies [13, 14]. Our study showed that the effect of SO_2 was larger than that of PM_{10}. Moreover, we found that improvement in air quality is associated with reduction of risk of acute mortality, ascribed both to SO_2 and PM_{10}. In general, the evidence regarding the role of exposure to SO_2 among determinants of acute mortality is less convincing compared to data on PM_{10}.

Sulphur dioxide is the predominant ambient air pollutant in Poland, both in urban and rural areas, mostly due to combustion of coal for industrial and domestic purposes. Predominant effect of exposure to SO_2 was apparent in the past, not only in our region but also in a large urban area of the city of Kraków – stronger in the elderly inhabitants [15, 16]. Moreover, the APHEIS component placed in Kraków revealed that SO_2 was the only statistically significant variable explaining changes in day-to-day cardiovascular mortality [17]. Due to a shared legacy of economic development the problem may have a regional dimension, thus affecting tens of millions of people in this part of Europe [17, 18]. From a global perspective the burden of SO_2-related impact on human health goes beyond the European estimates, as documented by studies in China [19]. It is also of relevance that even in countries with low SO_2 concentrations in ambient air effect of this pollutant can play a role in determining acute mortality patterns [20].

Our study employed a time-series analysis, thus its results could be discussed in terms of assumptions and questions that are pertinent to this type of analysis. The magnitude of the estimated risk attributable to exposure gradient is similar to the published figures and this finding could be interpreted in favor of the reliability of our results [2-5, 17, 21]. We also saw a biologically plausible effect of low temperatures triggering increased mortality. Moreover, we believe that proportional decrease in the risk, dependent on the decrease in the pollutant's concentration ("SO_2 drop" > "PM_{10} drop") lends additional support to the credibility of our findings. In a broader sense, the question of the impact of air pollution on health cannot ignore potential contributions from such important factors as, for instance, general health status of the population, level of health care and provision of health services, occupational exposure, lifestyle (including smoking), dietary habits, etc. To our knowledge there is no convincing evidence that the quality and provision of health service have improved substantially between 1994 and 2001 in our region. On the other hand, life expectancy has increased by approximately 2 years over the examined period [22]. The resulting shift of the population composition towards older ages has increased the size of vulnerable subpopulation (the daily average count of total deaths increased from 24 to 34 in this group), but the shift did not translate to larger air pollution-related risk estimates in this subpopulation.

In considering policy implication it is of relevance that the results of time-series analyzes could substantially underestimate the benefits of air pollution control as shown by recent studies, including cohort observations [1, 8, 23, 24, 25]. Moreover, the risk estimates as documented by a time-series model could be translated to the loss of life expectancy [26].

Conclusions

In conclusion, the results of our conventional time-series analysis show that the improvement in ambient air quality is associated with a decrease in risk of total and cardiovascular/respiratory acute mortality. From that perspective our findings lend evidence-based support to the goals of current air pollution abatement programs in Poland.

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