Original Research

Relative Risk of Total and Cardiovascular Mortality in the Eldery as Related to Short-Term Increases of $PM_{2.5}$ Concentrations in Ambient Air

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Abstract

The aim of our study was to assess the impact of short-term ultrafine particle concentration changes in ambient air to daily total and cardiovascular mortality in the older population (65 years and above) living in Zabrze, a city located in the Silesia Region of Poland. The measure of this relationship was the relative risk (RR) of daily mortality related to a 10 μg/m³ increase in $PM_{2.5}$ concentrations.

It was determined during the study period from 2000-05 that 6,378 people aged 65 and above died in Zabrze. Cardiovascular diseases accounted for 61.9% of the total mortality during the same study period. The highest daily mortality was seen during the winter, which was more than the other remaining seasons. The relative risk of total and cardiovascular mortality were 1.004 (95%CI:-1.003-1.010) and 1.002 (95%CI:-1.011-1.015), respectively. It was also shown that the risk increased with longer exposure times, with the highest value of RR related to two weeks exposure of the population.

The daily risk of cardiovascular mortality in Zabrze, related to $PM_{2.5}$ concentrations, is similar to values given by other authors. The obtained results suggest that longer exposures expressed by moving average concentration, from 3-days to 14-days, contribute to the highest risk of cardiovascular mortality in older inhabitants.

Keywords: time-series study, relative risk, cardiovascular mortality, $PM_{2.5}$

Introduction

The impact of ambient air pollution on human health and the role of fine particulate matter ($PM_{2.5}$) in this relationship have been discussed for many years, and have been documented by numerous published studies [1-6]. Even though results of an earlier study applied over 30 years ago within the Kraków population suggest that reduction of annual mean $PM_{2.5}$ to 20 μg/m³ would result in 457 (95% CI: 117-816) deaths due to chronic effects of exposure, including 340 (95% CI: 119-578) deaths relating to cardiovascular mortality [7-8], we still lack the appropriate data describing the relative risk of death in population living in the middle to eastern European countries. There are three reasons which have lead to our research focus. First, it is known that diversification of various emissions and the

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temporal variation of the aerosanitary situation in particular regions may lead to various health effects [1]. Second, the population size of inhabitants (190,000 people) living in Zabrze is large enough to justify the validity of the method recommended for health risk assessment. Thirdly, air pollution levels observed in the city remain high, especially during the cold season [9]. Relatively high exposures to ambient air pollution justify the assessment of the impact of short-term ultrafine particle concentration changes in air to daily number of total deaths and deaths due to cardiovascular diseases in the older population living in Zabrze, a city located in the Polish region of Silesia. We decided to present data for an older population because the cardiovascular mortality in this age group is the highest. Data on total mortality have previously been published [10].

Experimental Procedure

To realize the established goals of this work, a time-series analysis was used, covering six calendar years in the period 2000-05. Data concerning the daily number of deaths and daily averages of quality of ambient air relates to Zabrze, an industrial city located in Silesia Voivodeship in Poland.

Mortality data was 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 – 10th edition (ICD-10). The category of deaths due to cardiovascular diseases included deaths with codes I00-I99, the database contained the records in two age categories: less than 65 years and 65 or more years.

Data on ambient air pollution was provided by the State Environmental Agency in Katowice. The 24-hour spatial average concentrations of PM_{10}, $PM_{2.5}$, SO_2, and NO_2 were measured for each day. Moreover, the Institute of Meteorology provided additional data such as daily mean temperature, daily mean relative humidity, and daily mean atmospheric pressure for each of the days within the study period. The data set included variables describing a climatic season and influenza epidemic [11].

Variability of the daily number of deaths and daily concentrations of pollutants was presented in two ways. First we used methods of descriptive statistics, where presentation of the pollutant concentration was based on tertile value of the concentration. A low-level concentration was established at a value below the 33rd percentile, a medium concentration between the range of 33% and 66% percentile, and a high concentration above 66%. Differences in mortality according to the accepted categories of pollution were assessed by analysis of variance (ANOVA test). Next, we assessed the relationship between daily mortality and daily concentrations of air pollutants using GLM procedure. Variables describing ambient air pollution were expressed as average 24-hour concentrations on the death day, day preceding death, and 3-days or longer (to 60 days) moving average concentrations of each pollutant (PM_{10}, $PM_{2.5}$, SO_2, NO_2) [10]. The formula used in multivariate Poisson regression model was:

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

A model tested the effect of the increase of air pollution concentration (single pollutant) by 10 μg/m³ on a daily number of deaths in different specific scenarios: 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 deaths and longer (3, 5, 7, 14, 30, 40, 50, and 60 days). The relative risk (RR) estimates the total and circulatory deaths in relation to a 10 μg/m³ increase in each pollutant were calculated using the formula:

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

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

Additionally, a percentage change in mortality was calculated as the (RR-1) times 100%. Interpretation of statistical significance of the results was based on the criterion $p<0.05$. Finally, all the calculations were performed using SAS statistical software (SAS Inc, Cary, NC, USA).

Results

During the study period from 2000 to 2005, 6,378 people aged 65 and above died in Zabrze. Analysis showed that out of the 6,378 within the study period, 61.9% were due to cardiovascular diseases and 5.2% died as a result of respiratory diseases. Unexpected deaths accounted for 5.6% of the total. Further analysis of available registry data of infectious diseases incidence in Poland confirmed the occurrence of two influenza episodes, in 2003 and 2005. In both cases, the influenza episode occurred between 16 February to 22 March [11] with no observable increase in the rate of mortality due to influenza in these periods.

Descriptive statistics concerning the number of deaths in the city are presented in Table 1. Mortality due to cardiovascular diseases and illnesses is highest in the eldery female population (65+ years) and significantly higher in the younger male population. Respiratory mortality and sudden deaths were higher in both younger and older inhabitants of Zabrze.

Table 2 shows descriptive data in range of ambient air quality in Zabrze. It was documented that in the study period (from 01.01.2000 to 31.12.2005) the total number of days with exceedance of limit value [12] for $PM_{2.5}$ concentration (25 μg/m³), PM_{10} (50 μg/m³), and SO_2 (125 μg/m³) were 295, 448, and 15 days, respectively. These exceedances were associated with the cold season (fall-winter). Figs. 1-2 show changes in daily number of deaths in older inhabitants of Zabrze (aged 65 and above years) according to the quality of air. The obtained results suggest that the highest mortality were associated with days that had a higher level of concentration of particular pollutants.

Table 1. Basic descriptive data of total and specific mortality in Zabrze population, 2000-05.

Variable			Number	Daily mean	Standard Deviation
Total deaths	population aged<65 years	Total	3,929	1.8	1.4
		Female	1,222	0.6	0.7
		Male	2,707	1.2	1.1
	population aged +65 years	Total	6,378	2.9	1.8
		Female	3,523	1.6	1.3
		Male	2,855	1.3	1.1
	total population	Total	10,307	4.7	2.3
		Female	4,745	2.2	1.5
		Male	5,562	2.5	1.6
Sudden deaths	population aged<65 years	Total	376	0.2	0.4
		Female	77	0.04	0.2
		Male	299	0.1	0.4
	population aged +65 years	Total	219	0.1	0.3
		Female	105	0.05	0.2
		Male	114	0.05	0.2
	total population	Total	595	0.3	0.5
		Female	182	0.08	0.3
		Male	413	0.2	0.4
Deaths due to cardiovascular diseases	population aged <65 years	Total	1,020	0.5	0.7
		Female	302	0.1	0.4
		Male	718	0.3	0.6
	population aged +65 years	Total	3,348	1.5	1.3
		Female	1,990	0.9	0.9
		Male	1,358	0.6	0.8
	total population	Total	4,368	2.0	1.5
		Female	2,292	1.0	1.1
		Male	2,076	0.9	1.0
Deaths due to respiratory diseases	population aged <65 years	Total	124	0.06	0.2
		Female	36	0.02	0.1
		Male	88	0.04	0.2
	population aged +65 years	Total	360	0.2	0.4
		Female	181	0.08	0.3
		Male	179	0.08	0.3
	total population	Total	484	0.2	0.5
		Female	217	0.1	0.3
		Male	267	0.1	0.4

The results of ANOVA test confirmed statistically significant relationships for each pollutant. Table 3 shows results of multivariate analysis in range of regression coefficients and their 95% confidence intervals. The daily risk of cardiovascular death increases in the older population from 0.2% to 0.5% in relation to increases in the daily average $PM_{2.5}$ concentration by 10 µg/m³. The values depend on the time of exposure with a comparably higher risk for a longer time of exposure. Simply, as the time of exposure gets longer, the risk gets higher. A similar effect has been documented for cardiovascular mortality in the total population (Table 3). A higher percentage of increase of 0.6 or 1.1% was evident in the female population. This increase was adequately dependent on exposure expressed by daily or 3-day moving average concentrations. Finally, the obtained results confirmed statistically significant relative risk of cardiovascular mortality related to increase of $PM_{2.5}$ concentration for longer time of exposure, expressed by 7 or 14-days moving average concentrations in the older population (Fig. 3). Sulphur dioxide was the most dominant means for increasing daily death due to cardiovascular disease.

Discussion of Results

The results obtained from this study suggest that the relative risk of daily mortality related to short-term $PM_{2.5}$ concentrations in ambient air in Zabrze is similar to those given by other authors [1-4]. Mean value of daily mortality was higher during days with higher levels of concentration for each pollutant (Figs. 1 and 2). The highest and statistically significant relative risk of cardiovascular mortality related to increases of $PM_{2.5}$ concentration was characteristic for longer time of exposure, expressed by 7- or 14-day moving average concentrations of pollution (Fig. 3). It should be noted that the daily risk of death increases with increasing time of exposure, as well as a decrease of precision as expressed by the confidence intervals. The most sensitive group to high concentrations of pollutants was the elderly, described previously as inhabitants above 65 years of age [10, 13-14]. The most statistically significant relationships were associated with older women. Similarly, the higher risk of death in the elderly population, especially women, in response to $PM_{2.5}$ pollution was similar to findings of other studies [3, 12-18]. Temperature was a serious confounder in

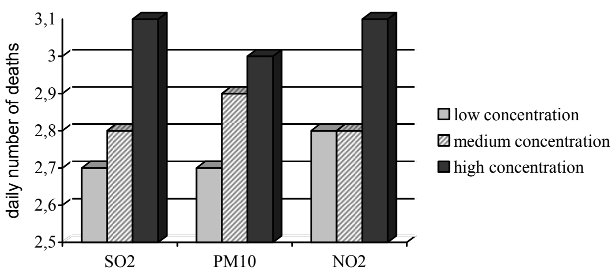

Fig. 1. Daily number of total deaths in older (65+) inhabitants of Zabrze according to concentrations of particular ambient air pollution.

Table 2. Descriptive data of pollutant concentrations in ambient air, Zabrze in 2000-05.

Pollution	Descriptive statistics of air pollutant concentrations [μg/m³]					
	Mean	Min.	Max.	Perc. 33%	Perc. 66%	SD
SO_2 (daily limit value 125 μg/m³)	35.7	2.6	266.2	21.6	36.8	25.2
$PM_{2.5}$ (annual limit value 25 μg/m³)	40.5	4.9	323.7	21.8	40.0	34.5
PM_{10} (daily limit value 50 μg/m³)	40.8	5.6	407.5	26.0	42.4	28.1
NO_2 (annual limit value 40 μg/m³)	26.9	6.0	87.0	21.3	29.2	11.2

Table 3. Relative risk of death due to cardiovascular diseases in eldery inhabitants of Zabrze related to an increase of ambient air pollution concentration by 10 μg/m³, in 2001-02.

Mortality	Pollution	Exposure	Relative risk (RR)	95% Confidence interval (CI)	Statistical significance p
Deaths due to cardiovascular diseases in total older population (65+years)	SO_2	Day of death	1.008	-1.011-1.027	0.3
		3 days moving average	-1.010	-1.009-1.032	0.2
	PM_{10}	Day of death	1.010	-1.004-1.023	0.1
		3 days moving average	1.014	-1.003-1.030	0.1
	$PM_{2.5}$	Day of death	1.002	-1.011-1.015	0.7
		3 days moving average	1.005	-1.011-1.021	0.5
Deaths due to cardiovascular diseases in older male population (65+ years)	SO_2	Day of death	-1.020	-1.051-1.011	0.2
		3 days moving average	-1.016	-1.049-1.018	0.3
	PM_{10}	Day of death	-1.011	-1.034-1.012	0.3
		3 days moving average	-1.010	-1.037-1.018	0.4
	$PM_{2.5}$	Day of death	-1.005	-1.026-1.016	0.6
		3 days moving average	-1.004	-1.029-1.021	0.7
Deaths due to cardiovascular diseases in older female population (65+ years)	SO_2	Day of death	1.026	1.002-1.049	0.03
		3 days moving average	1.029	1.002-1.051	0.03
	PM_{10}	Day of death	1.022	1.005-1.039	0.01
		3 days moving average	1.028	1.007-1.048	0.008
	$PM_{2.5}$	Day of death	1.006	-1.01-1.023	0.4
		3 days moving average	1.011	-1.009-1.032	0.2

the relationship. It should be noted that the number of deaths was significantly higher in winter than in summer. This observation is in agreement with other published data [19-20].

It is worth noting that the results obtained in our study describing the percentage increase in the number of deaths in Zabrze in response to increased concentrations of $PM_{2.5}$ to 10 mg/m³ are similar to those of other authors [1-4]. Our study clearly shows that increases in the daily concentration of $PM_{2.5}$ above a conventional unit led to an increase in total mortality risk in the elderly population in Zabrze by 0.4% (95% CI: -0.3-1.0%), and taking into account exposure from three days preceding death of up to 1.2% (95% CI:0.5-2.0%) is similar to the values quoted by Pope [1]. Two different studies in Shanghai and California presented similar values to our findings on daily exposure and mortality risk. In the study conducted in Shanghai, an increase in the mean value of concentration of two days resulted in an increase in total mortality of 0.36% (95% CI: 0.11-0.61%) [4], while the California study also showed similar effects with values of 0.6% (95% CI: 0.2-1.0%) [3].

With regard to the risk of deaths due to cardiovascular disease, increases in 3 days moving average of $PM_{2.5}$ concentration in Zabrze were associated with increases in the number of deaths by 0.5%, while in the Shanghai study a 2-day increase in pollutant concentrations led to mortality

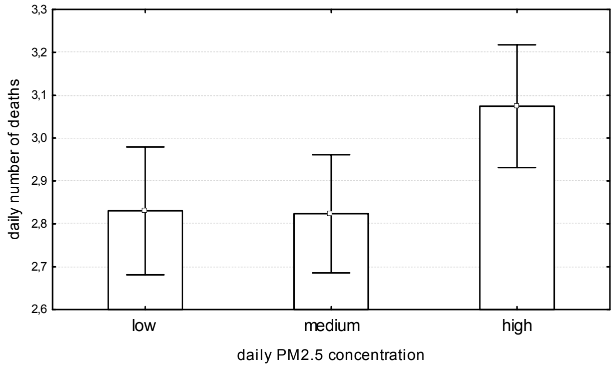

Fig. 2. Daily number of total deaths in older (65+) inhabitants of Zabrze, according to the category of $PM_{2.5}$ concentration in ambient air.

increasing by 0.41% [4]. Slightly higher risk was observed in a U.S. study by Franklin et al., where an increase in the concentrations of fine particulate to 10 mg/m³ showed an increase in the number of deaths by a total of 1.21% (95% CI :0.29-2.14%) [5]. Revealed differences regarding the risk of deaths are probably due not only to demographic, social and economic factors within a population, but also are the result of diverse chemical composition and the measured dust concentration levels, and duration of exposure.

New published data confirmed that more evidence is needed in identifying the specific components and sources of the particle composition in public health [21]. It has been documented that exhaust fumes from vehicles, fuel oil combustion, and road dust had statistically significant associations with cardiovascular mortality. Other data confirmed that cardiovascular mortality series exhibited different local combustion sources and seasonal patterns in different cities in the United States of America [22, 23]. The PM components associated with mortality in Detroit appear most associated with warm-season secondary aerosols and traffic markers. In Seattle, the species associated with mortality include those for cold-season traffic and other combustion sources, such as residual oil and wood burning [22].

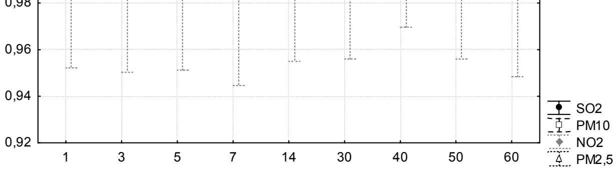

Fig. 3. Relative risk of deaths due to cardiovascular diseases in older (65+) inhabitants of Zabrze.

It was also shown in our study that the measured size of the health risks depends largely on the duration of exposure. It has a different dimension in the case of short-term, one-day exposure to pollution and is much larger with longer (e.g. several days or even months) exposure [1]. Moreover, some authors believe that no matter the type of study used, health risks estimated on the basis of ecological studies using either time series or cohort study with a duration of exposure of 60 days would be similar [24].

Recent studies suggest that short-term increases in concentrations of fine particulate matter ($PM_{2.5}$) in the ambient air also lead to an increase in personal exposure and for those people who spend most of their time at home (e.g. sick or old) [25]. An important voice in this debate is the perception of French researchers, who demonstrated that personal exposure of the inhabitants of Paris to fine particles $PM_{2.5}$ is much higher indoor (in homes and offices) than outdoors [26]. Given the large variability of pollution concentrations from day to day, it is necessary to track the health effects of variation in such a short time. Observed regional differences in air quality should lead to separate, local measurements of health effects. A major drawback for this type of research is often a lack of complete data on the state of ambient air, including concentrations of $PM_{2.5}$ in either the particular region or city [27]. Such deficiencies also exist in our country; we often have fragmentary data that do not reflect the total health risks for the population [28]. A similar situation was also a concern in our study, with systematic data on concentrations of $PM_{2.5}$ in the Silesia region only available for Zabrze. Among the recommendations presented in the last meeting of the management committee and members of working groups of COST 633 (Brussels 13-15.03.2008) was an emphasis that, for purposes of health policy issues, the collection of evidence should be sufficient for monitoring of PM_{10} concentrations instead of $PM_{2.5}$ for risk assessment health [29]. It was agreed that the best indicator of exposure will be ultra-fine particles with diameters less than 1.0 microns. Their major source in the environment remained combustion of vehicle fuels (petrol, oil), and tobacco smoking, burning of wood in fireplaces, and stoves and gasoline burning. This evidence also is supported by the opinion of 14 independent experts in epidemiology, toxicology, and clinical medicine, who suggest that concentrations of $PM_{2.5}$ in Europe remain at similar levels while concentrations of smaller particles are constantly growing due to traffic [30]. Current data in the Katowice Agglomeration confirm that fine particulates were the predominant fraction of suspended particles in indoor air [31].

An important premise for future research directions are cohort studies initiated in the 7th Framework Program of the EU acronym ESCAPE (European Study of Cohorts for Air Pollution Effects), which in a more objectified manner evaluate the health risks in connection with long-term exposure to air pollution (e.g. $PM_{2.5}$). The program is a scheduled ESCAPE multicentre study involving several European countries to evaluate the impact of air pollution on the risk of death due to respiratory and cardiovascular diseases [32]. Time series analysis has also been widely used.

Conclusions

The daily risk of total and specific mortality in Zabrze related to $PM_{2.5}$ concentrations is higher in older inhabitants (65 years and above) and is similar to values given by other authors.

The obtained results suggest that the most precise scenario useful for assessment of short-term health effects (e.g. total and specific daily mortality) related to particulate ambient air pollution in Zabrze is the presentation of longer exposure expressed by moving average concentration, from 3-day to 14-days. Similar observation is applicable to the gaseous air pollutants sulphur dioxide and nitrogen oxides, for which relative risk of death was larger for longer time of exposure.

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