Ambient PM2.5 Exposure and Mortality Due to Lung Cancer and Cardiopulmonary Diseases in Polish Cities.

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Abstract

Air pollution, one of ten most important causes of premature mortality worldwide, remains a major issue also in the EU, with more than 400,000 premature deaths due to exposure to $PM_{2.5}$ reported yearly. The issue is particularly significant in Poland, where there is the highest concentration of $PM_{2.5}$ among the EU countries. This study focused on the proportion of mortality due to lung cancer and cardiopulmonary diseases attributable to $PM_{2.5}$ in eleven biggest Polish cities in the years 2006–2011. The findings demonstrate that the mean annual concentration of $PM_{2.5}$ varied from 14.3 to 52.5 μg/m^3. The average population attributable fractions varied from 0.195 to 0.413 in case of lung cancer and from 0.130 to 0.291 for cardiopulmonary diseases. Such substantial values of this ratio translate into a considerable number of deaths, which ranged between 9.6 and 22.8 cases for lung cancer and 48.6 to 136.6 cases for cardiopulmonary diseases per 100,000 inhabitants. We conclude that the impact of $PM_{2.5}$ concentration on the incidence of premature deaths is unduly high in Polish cities.

1. Introduction

The European Environment Agency (EEA) estimates that between 2011 and 2013 9-30% of the urban population in the EU is exposed to the concentrations of PM_{10} and $PM_{2.5}$ (particulate matter with an aerodynamic diameter of less than 10 μm and 2.5 μm, respectively) exceeding the limit values (in accordance to the Directive 2008/50/EC of the European Parliament and of the Council on ambient air quality and cleaner air for Europe (CAFE Directive)). The proportion of the EU population exposed at a level exceeding the limit values has been decreasing in recent years (in accordance with EEA reports from 2012 to 2015). However, in terms of the concentration of particulate matter recommended by the World Health Organization (WHO 2006), the proportion of the urban population in the EU exceeding healthy levels has been higher for some years and currently reaches between 61 and 93% (EEA 2015).

Exposure to high levels of air pollution is associated with a wide range of acute and chronic diseases, especially respiratory and cardiovascular outcomes (WHO 2014; Balmes 2009), as well as diseases of the central nervous system (Kalkbrenner et al. 2015; Volk et al. 2013) and incidents of rheumatoid arthritis (Essouma & Noubiap 2015). Due to the high concentrations of air pollutants typically present in cities, urban populations are particularly affected by the adverse effects resulting from breathing polluted air. This is an important social and economic problem, especially given that approximately 75% of the European population lives in cities (Crosette 2010). The WHO estimates that worldwide particulate pollutants are responsible for about 8% of deaths due to lung cancer, 5% due to cardiovascular diseases and

3% due to respiratory infections (WHO 2009). A total 3.7 million premature deaths have been attributed to atmospheric pollution worldwide in 2012 (in both urban and non-urban populations) (WHO 2014b). A similar value in their analysis received Lelieveld et al. (2015). They showed that air pollution – mainly $PM_{2.5}$ – is responsible globally for 3.3 million deaths, with the larges impact on premature mortality in Asian countries (China and India), where the air pollutants in a substantial part are emitted from the residential sources. In the EU in 2015, the number of premature deaths per year attributable to exposure to $PM_{2.5}$ exceeds 400,000, a figure that is some 30,000 lower than for the previous year (EEA 2015). Although the number of deaths attributable to exposure to $PM_{2.5}$ is decreasing in Europe as a whole, in countries where the problem of air pollution is particularly large (Poland, Bulgaria), an increase in the number of deaths attributable to air pollution has been estimated over the same period. Moreover, in the EU 16,000 premature deaths have been attributed to exposure to tropospheric ozone (no change on the figures for previous years) and more than 70,000 of deaths have been attributed to exposure to nitrogen dioxide.

After careful consideration and analysis of available scientific literature (on both epidemiological studies and mechanistic studies), in November of 2013 the International Agency for Research on Cancer (IARC) deemed that there is sufficient scientific evidence on the relationship between exposure to air pollution and the incidence of lung cancer as well as bladder cancer. Particulate matter as a major component of air pollutants was also classified as a Group 1 carcinogen (carcinogenic to humans) due to enough evidence of association of increasing risk lung cancer and exposure to high concentrations of PM (IARC 2013).

The aim of this study was to estimate the proportion of mortality from lung cancer and cardiopulmonary diseases that can be attributed to exposure to concentrations of $PM_{2.5}$ in ambient air in selected Polish cities.

2. Material and methods

2.1. Material

Data from 2006-2011 on concentrations of particulate matter in the ambient air (both $PM_{2.5}$ and PM_{10} fractions) were obtained from the General Inspectorate of Environmental Protection (repository of the data collected by the State Environmental Monitoring). Aggregated annual mortality data for the populations of 11 urban agglomerations in Poland (cities with a population above 250,000) were acquired from the reports of the Department of Epidemiology in the Centre of Oncology (lung cancer) and the Central Statistical Office Local Data Bank (cardiopulmonary and all-cause mortality).

2.2. Methods

Exposure to air pollution in each urban agglomeration (hereafter referred to as “city”) was assessed as the population's exposure to $PM_{2.5}$, mean 1-hour concentrations of $PM_{2.5}$ (subsequently aggregated to 1-year mean values). Due to the fact that in some air monitoring stations $PM_{2.5}$ concentration has not been measured in all relevant years, these were estimated on the basis of PM_{10} concentrations for the same city; conversion factors from PM_{10} to $PM_{2.5}$ were determined using the results of the joint measurements of both fractions of the same station (if available) or on measurements from different stations located in the same city. It was assumed that these ratios are typical for the particular city. Depending on city their values ranged from 0.61 to 0.84.

To calculate the burden of mortality that can be attributed to $PM_{2.5}$ (population attributable fractions (PAF) based on relative risk (RR) of mortality arising from the exposure to $PM_{2.5}$) the exposure-response functions presented in the report on the European Perspectives on the Environmental Burden of Diseases (Hänninen & Knol 2011) were used. Measures of relative risk normalized for unit exposure to $PM_{2.5}$ in the case of lung cancer and cardiopulmonary diseases were taken from the results of an American study (Pope et al., 2002); those for all-cause mortality were taken from a report of the World Health Organization (WHO 2013).

3. Results

The annual mean $PM_{2.5}$ concentrations for 2006-2011 in all eleven Polish cities ranged from 14.3 μg/m^3 to 52.5 μg/m^3 (Fig. 1), reaching the highest values in the cities of southern Poland (Cracow, Katowice), where the emission of air pollutants results primarily from municipal and household sources (so-called low-stack emission) as well as road transport and heavy industry. The lowest concentrations were observed in cities located in the east (Bialystok, Lublin) and north (Gdansk, Szczecin) of the country, where the density of emission sources is lower and there are better climatic conditions for dispersion of air pollutants. For the period of interest, the mean annual concentrations of PM_{10} and $PM_{2.5}$ exceeded the limit values according to the CAFE Directive in 7 and 8 (out of 11) cities, respectively. In 5 of the cities, concentrations of $PM_{2.5}$ and PM_{10} in 2011 increased in comparison with levels in 2006.

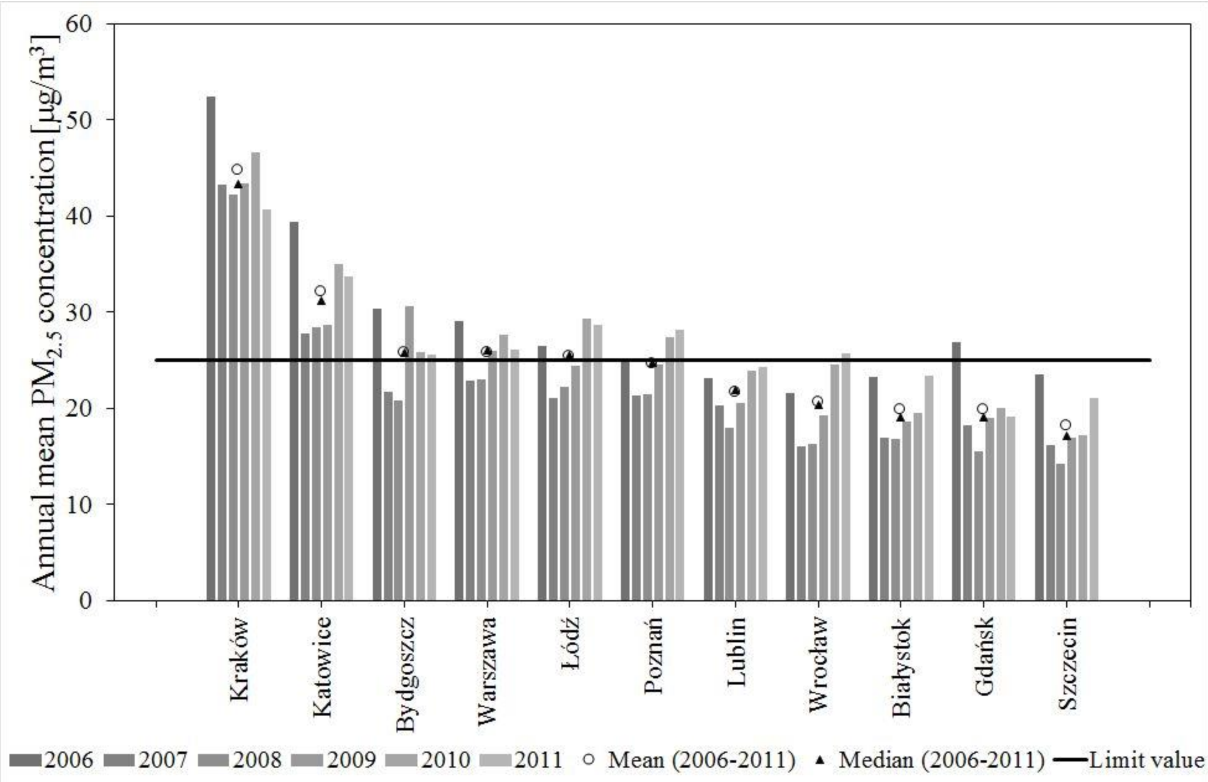

Fig. 1 The annual average concentration of $PM_{2.5}$ in Polish cities in the period 2006-2011 ($PM_{2.5}$ limit value – 25 μg/m^3)

Relative risks of mortality associated with exposure to $PM_{2.5}$ which were calculated for individual years and considered urban areas, were used to the estimation of the population attributable fraction, i.e. the fraction of the population the deaths of which would be prevented if the concentration of $PM_{2.5}$ was reduced to the hypothetical level of zero. Mean values of

PAFs for the years 2006-2011 in terms of mortality from lung cancer, cardiopulmonary diseases and total mortality due to natural causes demonstrated similar patterns as the mean concentrations of $PM_{2.5}$ and were presented in Table 1.

Table 1 Mean values and 95% confidence intervals of population attributable fractions for mortality from lung cancer, cardiopulmonary diseases and total mortality (non-violent) in analysed cities in the period 2006-2011

City	Lung cancer	Cardio-pulmonary diseases	All-cause (natural)
		Mean (95% CI)	
Cracow	0.413 (0.391, 0.437)	0.291 (0.278, 0.304)	0.242 (0.233, 0.251)
Katowice	0.318 (0.295, 0.342)	0.218 (0.207, 0.230)	0.180 (0.172, 0.189)
Bydgoszcz	0.265 (0.246, 0.284)	0.179 (0.170, 0.189)	0.147 (0.141, 0.154)
Warsaw	0.264 (0.254, 0.276)	0.179 (0.174, 0.185)	0.147 (0.144, 0.151)
Lodz	0.261 (0.246, 0.277)	0.177 (0.170, 0.184)	0.145 (0.140, 0.150)
Poznan	0.254 (0.242, 0.268)	0.172 (0.166, 0.178)	0.141 (0.137, 0.146)
Lublin	0.228 (0.218, 0.239)	0.153 (0.149, 0.158)	0.126 (0.122, 0.129)
Wroclaw	0.217 (0.201, 0.234)	0.146 (0.138, 0.154)	0.119 (0.114, 0.125)
Bialystok	0.210 (0.199, 0.222)	0.141 (0.136, 0.146)	0.115 (0.112, 0.119)
Gdansk	0.210 (0.196, 0.225)	0.141 (0.134, 0.148)	0.115 (0.110, 0.120)
Szczecin	0.195 (0.183, 0.207)	0.130 (0.124, 0.136)	0.106 (0.102, 0.110)

The data presented in Table 1 indicate that the fraction of mortality due to the health outcomes of interest attributable to exposure to $PM_{2.5}$ is directly proportional to its concentration in the ambient air in individual cities, varying significantly between cities and similarly reaching the highest values in Cracow and Katowice (southern part of the country) and the lowest in Bialystok (eastern part) as well as in Gdansk and Szczecin (northern Poland).

The results of population attributable fractions and data on the total annual number of deaths from the health outcomes of interest, were used to calculate the number of deaths attributable to $PM_{2.5}$ in ambient air. For this purpose data on the population living in each city was also used. Given the size of the population of these cities and the total number of deaths due to considered causes, most of the estimated mortality attributable to exposure to $PM_{2.5}$ occurs in Warsaw, Cracow and Lodz. Detailed information on attributable cases of lung cancer and cardiopulmonary diseases are given in Fig. 2 and Fig. 3.

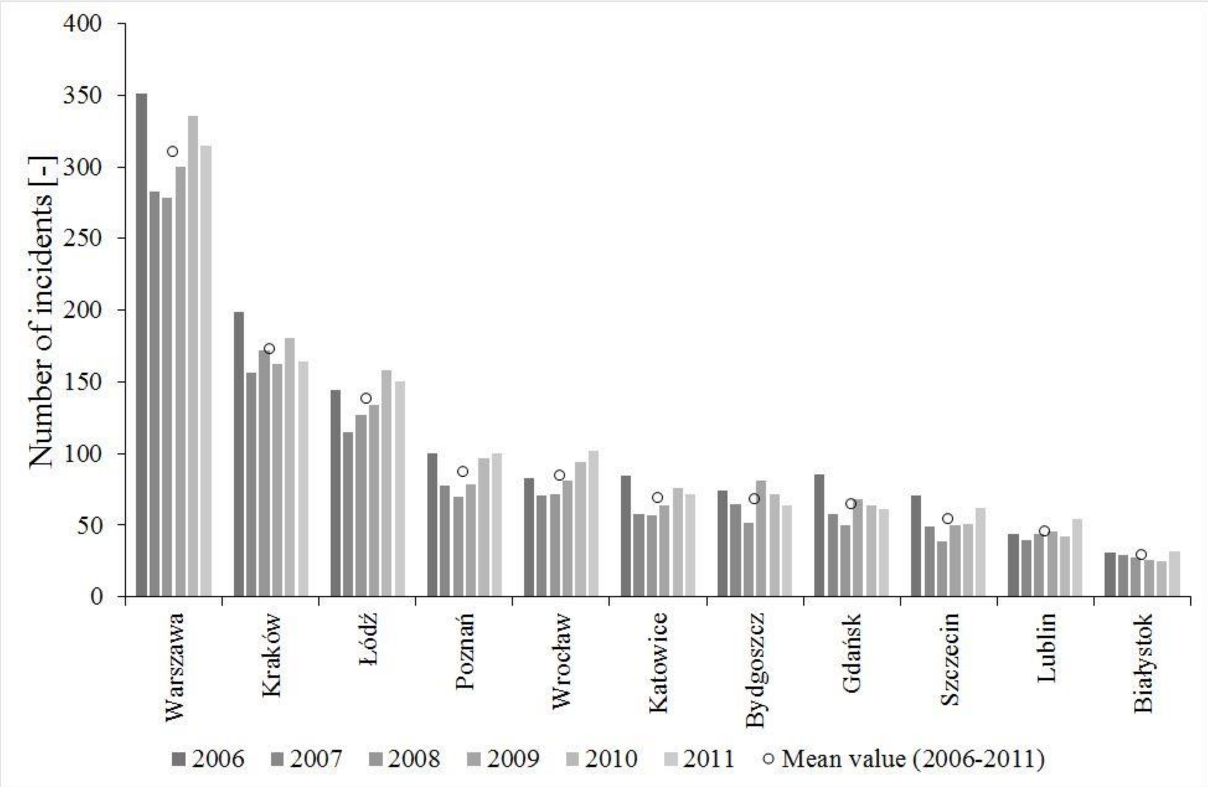

Fig. 2 Lung cancer mortality attributable to ambient $PM_{2.5}$ in Polish cities in the period 2006-2011

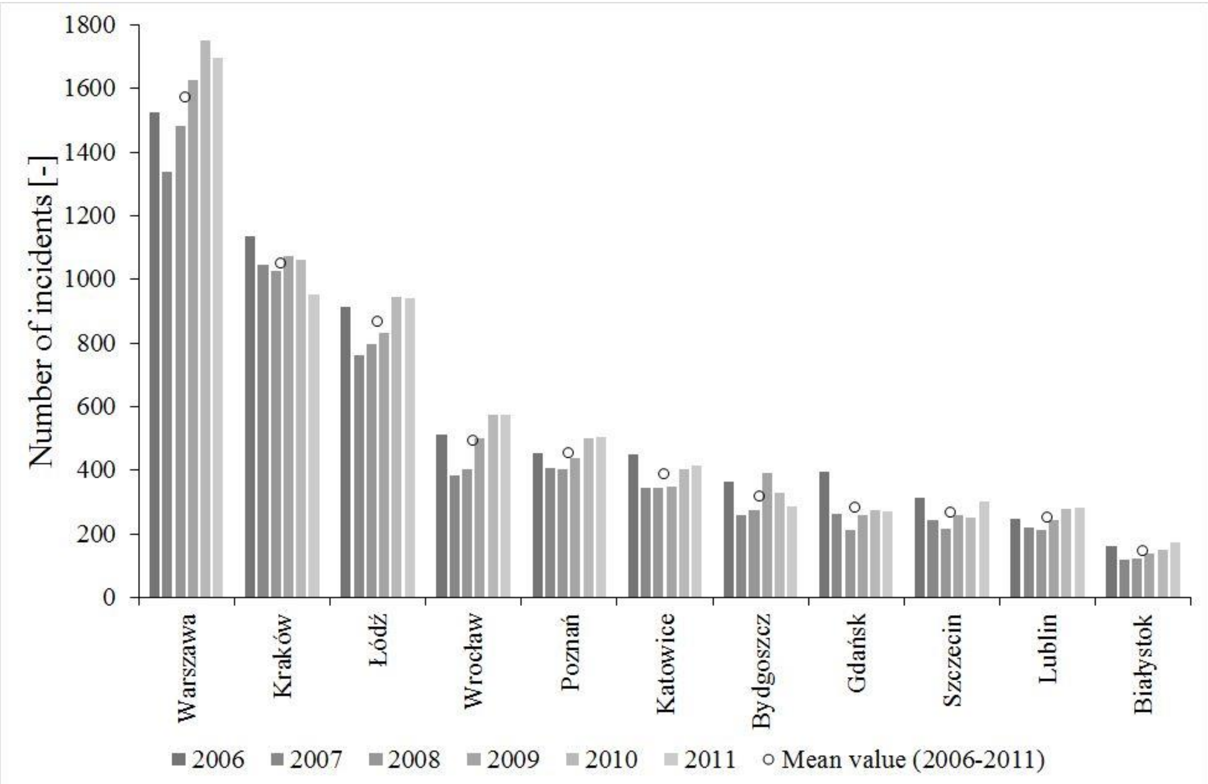

Fig. 3 Cardio-pulmonary mortality attributable to ambient $PM_{2.5}$ in Polish cities in the period 2006-2011

Considering the heterogeneity in levels of $PM_{2.5}$ to which the inhabitants of different cities are exposed, in order to more clearly present the scale of the estimated health impacts, a conversion of deaths attributed to $PM_{2.5}$ in relation to 100,000 residents was made. Table 2 presents the mean population in cities between 2006 and 2011 and Fig. 4 depicts the deaths attributed to $PM_{2.5}$ due to all natural causes as well as cardiopulmonary diseases and lung cancer mortality.

Table 2 Average population in individual cities in the period 2006-2011

City	Population
Warsaw	1.706.932
Cracow	756.559
Lodz	743.112
Wroclaw	632.299
Poznan	557.758
Gdansk	457.596
Szczecin	408.328
Bydgoszcz	361.455
Lublin	350.540
Katowice	310.933
Bialystok	294.377

The most common causes of death attributable to exposure to $PM_{2.5}$, particularly in the case of lung cancer and cardiopulmonary diseases concern cities characterized by the highest concentrations of this pollutant (Cracow and Katowice). Comparable rates were recorded in Lodz, where the concentration of $PM_{2.5}$ are noticeably lower. Other factors that increase mortality such as age (the risk factor most associated with mortality from cancer and cardiovascular disease) clearly play a role in increasing the number of attributable cases. Moreover, in Lodz, which was an industrial city may reveal the effects of exposure to high concentrations of air pollutants that occurred in the city during intense activity of light industry (this is due to the lack of taking into account the latency period) Definitely the lowest mortality rates per 100,000 inhabitants concerns Bialystok, although only slightly higher values are observed in Szczecin and Gdansk (cities located in the north Poland, in the immediate vicinity of the Baltic Sea).

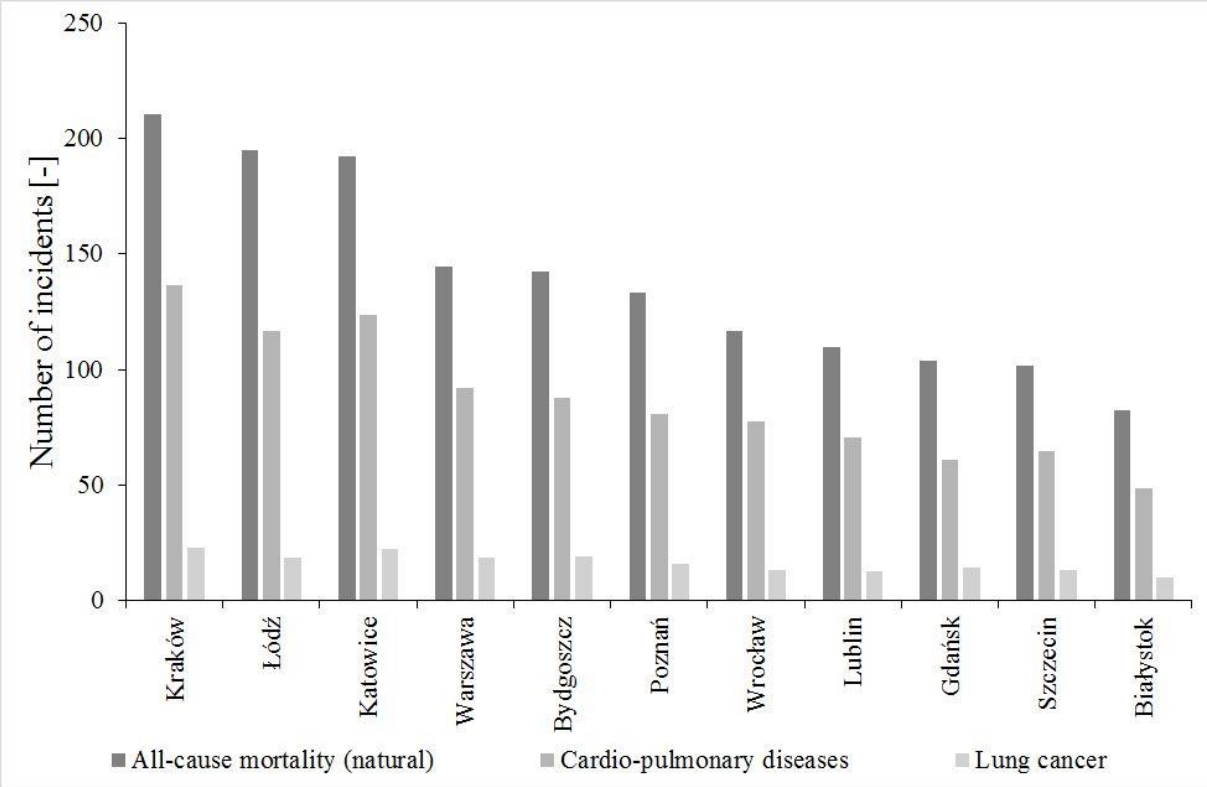

Fig. 4 The average all natural causes, lung cancer and cardio-pulmonary mortality per 100,000 inhabitants attributable to ambient $PM_{2.5}$ in Polish cities in the period 2006-2011

4. Discussion and conclusion

This study presents estimates of the total number of deaths from all natural causes as well as due to lung cancer and cardiopulmonary diseases that can be attributed to exposure to $PM_{2.5}$. The results, indicate that $PM_{2.5}$ has a noticeable impact on the number of deaths. It was clearly observed that in cities characterized by the highest levels of particulate matter (Cracow, Katowice) shares of deaths attributed to $PM_{2.5}$ against the background of the total number of deaths are the highest.

While the results of this study provide very useful information for policy makers regarding the potential impact of air pollution on public health in Poland, the relatively simple approach used to calculating the attributable cases has some limitations. Firstly, the same exposure to concentrations of $PM_{2.5}$ has been assigned to all inhabitants of a given particular city, thereby ignoring the intra-city variation in true exposure that exists. This simplification was made due to the limited number of air quality monitoring stations in each of the cities of interest (in some cities monitoring results were available for only one station) and due the lack of possibility of referring specific and differentiated concentrations of $PM_{2.5}$ to certain fraction of the population living in these cities. In carrying out this analysis, this lack in sufficient density of sampling stations was a finding of some considerable importance in terms of environmental and public health policy: only with adequate network of air pollution monitors can a more complete picture of the impacts of air pollution on the health of Polish citizens be understood. Having regard the ability to expand the air pollution monitoring system in cities, in the course of further analyses it would be possible to use the tools for modelling distributions of $PM_{2.5}$ in the agglomeration, which can help in getting more reliable results.

Due to the use of aggregated mortality data, there was no way of estimating the impact of effect modification due to tobacco use (see (Kuenzli et al. 2005)) or other potentially important covariates e.g. socioeconomic status. Furthermore it should be emphasized that relative risks normalized to a unit exposure to $PM_{2.5}$ were used, which are derived from studies conducted mostly in North American populations. It is likely that these relative risks should not be transferred directly for use in Polish populations without recognising the potential for introducing bias due to differences in distributions of (unmeasured) covariates such as tobacco use, socioeconomic status, ethnicity etc. However, due to the lack of epidemiological studies in this field in Poland it is currently not possible to verify the magnitude and direction of such a bias.

Taking into account the generally high levels of particulate matter pollution in Polish cities (one of the highest among all EU countries) and exceedances not only of the restrictive WHO guidelines regarding the recommended concentrations of $PM_{2.5}$ in the ambient air, but also much more liberal limits under the EU and national law, it should be noted that the contribution of the risk factor related to the impact of air pollution on mortality is relatively high.

Although there are research results indicating the lack of statistically significant relationships between exposure to particulate matter and cardiovascular (Wang et al. 2014) or respiratory (Dimakopoulou et al. 2014) diseases mortality, most of the research in this area indicates an increased mortality risk for those exposed to long-term and short-term impact of air pollution (including PM_{10} and $PM_{2.5}$). In many studies on similar issues, which were carried out in other countries, significantly lower concentrations of $PM_{2.5}$ in ambient air were found. Impact assessment of air pollutants on mortality in 22 cohort studies carried out in Europe showed that $PM_{2.5}$ concentrations ranged from 6.6 μg/m^3 to 31.0 μg/m^3 (Beelen et al. 2013). When compared with the cities of southern Poland, as demonstrated by the results presented in this paper, the exposure of the subjects in these cohorts was significantly lower. It has been found among them an increasing by 1.07 risk of mortality attributed to the increase of the concentration of $PM_{2.5}$ for every 5 μg/m^3, while pointing out that this pollutant was most closely associated with mortality in relation to all other types of air pollutants, which were included in the analyses (especially PM_{10}, NO_2, NO_x). An increasing risk of mortality for lung cancer and stroke has been observed, and in the case of deaths due to ischemic heart disease and respiratory diseases no changes in mortality risks were registered. Analyses regarding the same cohorts also indicated a statistically significant association between increasing concentration of $PM_{2.5}$ and the risk of mortality from cerebrovascular diseases, growing by 1.21 with increased concentration of $PM_{2.5}$ by each 5 μg/m^3 (Beelen et al. 2014). Dutch study on long-term exposure on traffic-related air pollutants and its association with mortality indicated that each 10 μg/m^3 increase of $PM_{2.5}$ concentration is associated with higher risk of mortality due to natural causes (RR=1.06), cardiovascular diseases (RR=1.04) and respiratory diseases (RR=1.07) (Beelen et al. 2008). In this study even slightly stronger associations with NO_2 (30 μg/m^3 concentration increase) were also ascertained. In a Brazilian study a 3,3%, 3.8% and 6.0% increase in daily mortality for all causes, cardiovascular and respiratory diseases respectively for an increase of PM_{10} concentration from the 10th to the 90th percentile was reported (Gouveia & Fletcher 2000). In turn, the research conducted in the United States showed an increase in total mortality risk of 1.06 with increasing concentration of $PM_{2.5}$ by 10 μg/m^3 (Pope et al. 2002) and in a Canadian cohort (Crouse et al. 2012) to the same growth of $PM_{2.5}$ concentration was assigned an increasing risk of natural deaths (RR=1.15) and ischemic heart disease (RR=1.31). 6% increase in the total mortality risk and 11% in the cardiopulmonary mortality (ischemic heart disease in particular) was indicated in the results of research on the long-term effects of exposure to $PM_{2.5}$ pollution, covering many areas of the world, including Asian countries (Hoek et al. 2013). In the Harvard Six Cities study (Laden et al., 2006) and other US study of 36 cities (Miller et al. 2007), there was found a significantly higher risk (28% and 76% respectively) of death due to cardiopulmonary diseases associated with an increase in the concentration of $PM_{2.5}$ by 10 $\mu g/m^3$. In the British cohort study almost no change of risk of death from cardiopulmonary diseases dependent on changes in air quality was found (Carey et al. 2013). Shah et al. (2013) showed a slight increase in the risk of hospitalization or death due to circulatory failure associated with growing concentration of $PM_{2.5}$ (about 1.02 per 10 $\mu g/m^3$ of $PM_{2.5}$). Considerably higher relative risks of morality are observed in studies carried out in China, where the problem of air pollution is one of the largest in the world. The study by Dong et al. (2012) demonstrated that the risk of death due to respiratory diseases is 1.67 per 10 $\mu g/m^3$ of PM_{10}. Other Chinese research (Kan et al. 2008) indicated growing mortality outcomes associated with increased concentration of PM_{10}. A 10 $\mu g/m^3$ increase of PM_{10} caused an increase of total, cardiovascular and respiratory mortality by 25%, 27% and 27% respectively. The effects were similar in cool and warm season except respiratory mortality which was considerably higher in winter season.

This study focused only on the 11 largest cities in Poland, as these are the ones currently monitored for air pollution on a routine basis. Given the presence of heavy industry and the use of low quality coal and other poor quality fuels for domestic heating in some of the many smaller cities in Poland, in particular those in the densely populated south-western part of the country, it seems likely that the current study results present a considerable underestimate of the public health impacts of air pollution in the country as whole.

The results presented in this paper represent a preliminary study on the assessment of the health impacts (in terms of mortality) due to fine particulate air pollution in Poland. The potential impacts of fine particulate air pollution on public health in Poland are potentially very high relative to other Member States of the European Union. Such public health impacts are associated with considerable costs in both social and economic terms. This study serves to indicate both the very limited information available for the accurate assessment of environmental quality of the majority of Polish cities and towns – indeed the whole country – and the lack of a developed infrastructure for assessing risks presented to the Polish population from environmental contaminants. Development of an improved integrated network of air pollution monitoring and funding epidemiological research towards improving understanding of the environmental determinants of health in Poland would serve to greatly improve the quality of a subsequent health impact assessment study, something which would ultimately help policy makers to reduce emissions, improve air quality and benefit public health.

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