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The Influence of Particulate Matter on Respiratory Morbidity and Mortality in Children and Infants

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Abstract

Air pollution is the most important environmental health risk leading to premature mortality, respiratory and other health problems. The aim of this study was to quantify its impact on infants and children in Warsaw (Poland), following the principles of Health Impact Assessment method. Particulate matter ($PM_{2.5}$ and PM_{10}) was considered as the indicator of air pollution. Exposure-response functions between air pollution and health impacts were employed based on the literature. According to the calculations, around 5,201 asthma symptoms and 234 hospital respiratory admissions were caused annually due to air pollution. Hospitalizations due to cardiovascular problems related to air pollution amounted to 13. The mortality among infants and children is relatively low and occurs mostly in the postneonatal period. Nonetheless, approx. 5 mortality cases were assessed to be air pollution-attributable. The study demonstrates a significant impact of air pollution on infants and children, which is manifested primarily as a range of respiratory problems.

Keywords

Air pollution • Children • Health Impact Assessment • Infants • Particulate matter • Respiratory diseases

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1 Introduction

A negative effect of air pollution on human health has been widely recognized. According to World Health Organization (2009), urban outdoor air pollution was worldwide the 14th of the 19 leading risk factors for mortality in 2004. A recent comparative risk assessment of burden of disease in 21 regions in the world (Lim et al. 2012) has demonstrated approx. 3.2 million deaths and more than 76 million disability-adjusted life-years related to air pollution in 2010. Scientific evidence of the increasing levels of exposure to air pollution (and particulate matter especially) and a growing risk of lung cancer led the International Agency for Research on Cancer (IARC) in 2013 to classify outdoor air pollution (and PM separately) as carcinogenic to humans (WHO 2013a). The WHO indicated that, globally, 3.7 million deaths are attributable to ambient air pollution, basing on the 2012 data. It is also estimated that the joint effect of household and ambient air pollution causes seven million of premature deaths yearly (WHO 2014).

Air pollution is the most important environmental health risk, which is supported by numerous epidemiological studies (Krzyzanowski et al. 2014; Beelen et al. 2014; Pope et al. 1995; Dockery et al. 1993). In particular, particulate matter (PM) air pollution is a major public health concern in urban areas (Brugha and Grigg 2014). PM consists of a mixture of solid and liquid particles suspended in the air that vary in number, size, shape, surface, area, chemical composition, solubility, and origin. Particle size is usually defined relative to a 50 % cut-off point at a specific aerodynamic diameter (such as 2.5 μm or 10 μm). In most locations in Europe, $PM_{2.5}$ constitutes 50–70 % of PM_{10} (WHO 2013b). The health effects of both short- and long-term exposure to PM_{10} and $PM_{2.5}$ are well documented, with no evidence of a safe level of exposure or a threshold below which no adverse health effects occur (Pope and Dockery 2006).

There is now substantial evidence that ambient air pollution is associated with increased mortality and morbidity in children (e.g., Beatty and Shimshack 2014; Lacasaña et al. 2005; Ward and Ayres 2004). The special vulnerability of children to exposure to air pollution is related to several differences between children and adults (WHO 2005), *inter alia*, the ongoing process of lung growth and development, incomplete metabolic systems, immature host defenses, and high rates of infection by respiratory pathogens. Moreover, children spend more time outdoors than adults, which increases their direct outdoor exposure (Schwartz 2004). Some authors also raise the issue of the implications of these air pollution-attributable health problems in youth, which may have long-lasting effects by impeding long-term human capital development (Beatty and Shimshack 2014).

The aim of this study was to quantify the annual impact of air pollution on infants and children in Warsaw (Poland), following the principles of Health Impact Assessment (HIA). Poland is a country which according to an Europe-wide study performed by the European Environment Agency (EEA 2013) of 2011 was one of the most polluted countries in the European Union. Moreover, recent research, which has been completed in Warsaw, indicated that traffic-related air pollutants significantly increase the risk of bronchi obstruction among people living in the proximity of main roads, compared to residents of rural areas (Badyda et al. 2013, 2014).

2 Methods

2.1 General Approach

The method used in this study follows the general guidelines on the assessment and use of epidemiological evidence for environmental health risk assessment recommended by WHO (2000). It consists of several steps and is based on the Health Impact Assessment (HIA) approach. Firstly, the environmental exposure and its distribution in the target population need to be specified. In case of a mixed exposure, which is typical for air pollution, the most reasonable indicator (or a group of indicators) has to be carefully selected and discussed. Secondly, the appropriate health outcomes (i.e., endpoints, such as chronic respiratory diseases incidence and prevalence, respiratory hospital admissions, etc.) are defined on the basis of estimated exposure and the availability of the necessary data. The next step involves adopting health risk estimates, i.e., exposure-response functions (ERFs), from epidemiological studies. These functions describe quantitatively the change of a specified health effect due to the change of exposure to a given amount of the specified agent. The information on ERFs can be obtained from pooled analyses or meta-analyses. After that, population baseline frequency measures for the selected health outcomes are derived in order to quantify the prevalence or incidence of the outcomes under consideration. Finally, the number of attributable cases is calculated, assuming that exposure gives rise to the health outcome – the relation explained by the distribution of the exposure in the target population, the adopted ERFs and the estimated baseline frequency of the health outcome in the target population (Krzyzanowski et al. 2002; WHO 2000). The impact assessed by means of HIA can be further economically evaluated (e.g., Jakubiak-Lasocka et al. 2014; Künzli et al. 1999) in order to help the decision-makers to judge the potential negative health effects of a policy, program, or project concerning specific population.

As implied above, the procedure for quantification of the expected health effects related to air pollution requires many assumptions and methodological decisions to be taken and large number of data to be collected. Therefore, to take into account an inherent uncertainty in the calculations, an 'at least' approach was applied at each step of this study. These methodological assumptions led to the results expected to be 'at least' attributable to air pollution (Künzli et al. 1999, 2000). In this way the impact of air pollution obtained in this study is expected to be underestimated rather than overestimated.

2.2 Population Exposure

Air pollution contaminates the atmosphere by a mixture of substances present at concentrations above their normal ambient levels, which produces undesirable effects on human, animals, vegetation, or materials (Seinfeld and Pandis 2006). Pollutants of major public health concern include particulate matter, carbon monoxide, ozone, sulfur dioxide, nitrogen oxides, and volatile organic compounds (Kampa and Castanas 2007; Künzli et al. 1999). The pollutants are often highly correlated. It is, therefore, impossible to strictly allocate observed effects to single pollutants. A pollutant-by-pollutant assessment would result in a significant overestimation of the health impact. The usual approach in the air pollution epidemiology consists of a selection of only one pollutant to be an indicator of the complex mixture (Künzli et al. 1999, 2000). In the present study, $PM_{2.5}$ and PM_{10} were considered as a source of attributable cases. The reason for that was, above all, the most convincing evidence for adverse health effects existing for PM (Brugha and Grigg 2014), which enabled the widest possible approach to the subject. Another point was that PM has been commonly used in other studies to assess the impact of air pollution on human health.

The exposure of infants and children in the city of Warsaw to $PM_{2.5}$ and PM_{10} was evaluated on the assumption that the whole population within the city borders has been exposed to the same level of air quality, indicated by the pollutant measurement data from outdoor monitoring sites. This is due to the lack of data that would allow to assign a particular part of the population to a specific monitoring site. The health effects of air pollution, depending on the time between the exposure and effect, can be divided into two broad categories: long-term and short-term (Pope and Dockery 2006). In both cases, the distribution of infants and children's exposure to the average annual concentration of $PM_{2.5}$ and PM_{10} was employed, rather than the exposure distribution for each and every day. To be in line with the methods used in previous studies (Künzli et al. 1999, 2000), it was assumed that the average level of particular pollutant at any day, corresponds to its annual mean level. Consequently, the sum of all daily effects across one year corresponds to the annual impact.

The annual average level of ambient $PM_{2.5}$ and PM_{10} for years 2011–2013 (Fig. 1) was derived from results of direct measurements

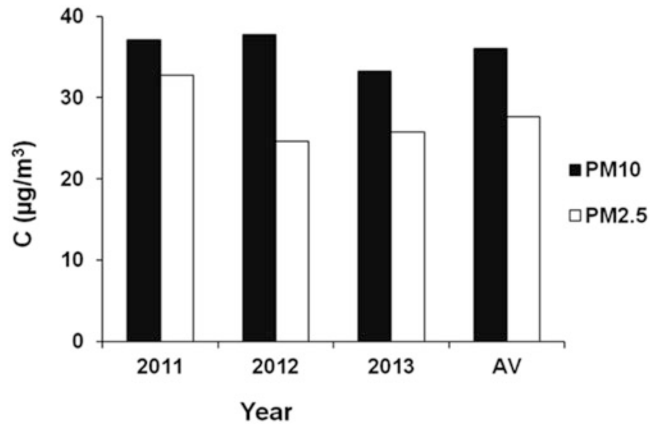

Fig. 1 Annual average concentration of $PM_{2.5}$ and PM_{10} for the years 2011–2013 and their average (AV)

carried out by the Regional Inspectorate of Environmental Protection in Warsaw (WIOS 2014). The monitoring system of air quality in Warsaw consists of 11 automatic and manual monitoring sites (as of 2014), eight of which are capable of measurement of PM_{10} level and four of $PM_{2.5}$. Yet it must be emphasized that the measurements from all the monitoring sites were not available, due to some internal problems leading to cancellation of the results and consequently not publishing them by WIOS. Thus, data on the concentration of PM_{10} ($PM_{2.5}$) came from six (four) monitoring sites in 2011, four (three) in 2012, and five (three) in 2013.

2.3 Health Effects and Risk Estimates

As already mentioned, there is large evidence in the literature over the negative influence of particles on various health outcomes among infants and children. Therefore, it seems substantial to integrate as much of the available information as possible by quantitative analyses of the results of individual studies. In the present study, the endpoints and the estimates of their effects in the form of relative risk (RR) for a given change in exposure were derived from ENHIS-1 (Environment and Health Information System – phase 1) – part of the APHEIS project (Air Pollution and Health: A European Information System) – which pays special attention to children, including the effects of PM_{10} on, *inter alia*, postneonatal mortality, hospital respiratory admissions, cough, and lower respiratory symptoms. The authors of this project were using the following criteria (in a graded order) in the selection process of RR:

- summary estimates from meta-analysis
- original studies involving large populations
- interrelated outcomes with high overall evidence of a causal contribution of air pollution.

It is worth noticing that this project was conducted in 31 European cities and one of its participant was Polish city of Cracow (APHEIS (ENHIS) 2005).

The estimates selected from the APHEIS project were completed with the data recently recommended by WHO (2013c), as part of HRAPIE (Health Risks of Air Pollution in Europe) project: recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone, and nitrogen dioxide. After the elimination of overlapping health effects, the scope of this study was widened to the following effects of PM_{10} and $PM_{2,5}$: all-cause mortality, hospital cardiovascular admissions, prevalence of bronchitis and incidence of asthma symptoms in asthmatic children. To conclude: from both projects all endpoints measuring the effects of particles on health of infants and children were derived and included in the present study.

All the selected health effects, with the defined populations, effect estimates (RR for 10 μg/m^3 increase with 95 % CI (Confidence Interval)), and the original source of ERFs are presented in Table 1. The effect estimates for the endpoints: hospital respiratory admissions

Table 1 Health outcomes with relative risks and data sources

Health effect	Population age group	Pollutant	RR for 10 μg/m^3 increase (95 % CI)	Source of ERFs	Source of health data
Total postneonatal mortality	1 month-1 year	PM_{10}	1.048 (1.022; 1.075)	Lacasaña et al. (2005)	CWO (2013)
Postneonatal respiratory mortality			1.216 (1.102; 1.342)		CWO (2013)
Postneonatal SIDS mortality			1.120 (1.070; 1.170)	Woodruff et al. (1997)	CWO (2013)
Cough	5–17 years		1.041 (1.020; 1.0511)	Ward and Ayres (2004)	n/a
Lower respiratory symptoms			1.041 (1.020; 1.617)	Ward and Ayres (2004)	n/a
Hospital respiratory admissions	<15 years		1.010 (0.998; 1.021)	Anderson et al. (2004)	CWO (2013)
Prevalence of bronchitis in children	6–12 (or 6–18) years		1.080 (0.980; 1.190)	Hoek et al. (2012)	n/a
Incidence of asthma symptoms in asthmatic children[a]	5–19 years		1.028 (1.006; 1.051)	Weinmayr et al. (2010)	CWO (2013) and Komorowski (2012)
Mortality, all-cause	All ages	$PM_{2,5}$	1.012 (1.005; 1.020)	WHO (2013c)	CWO (2013)
Hospital cardiovascular admissions			1.009 (1.002; 1.017)	WHO (2013c)	CWO (2013)
Hospital respiratory admissions			1.019 (0.998; 1.040)	WHO (2013c)	CWO (2013)

[a]Total person-days with asthma attacks
SIDS sudden infant death syndrome, *RR* relative risk, *ERF* exposure-response function

and prevalence of bronchitis in children were not statistically significant. However, the point estimates and the majority of the area covered by the confidence intervals demonstrated a negative influence of particles. In addition, a probabilistic sensitivity analysis was conducted.

2.4 Health Data

Most of the data on the prevalence or incidence of the selected outcomes in the target population were derived from a report of the city of Warsaw Office *The health status of residents of Warsaw in 2009–2011* (CWO 2013). As the data were reported for 3 years, the average was incorporated into calculations, in order to obtain a more robust annual estimation, neglecting some eventual singular deviations. Unfortunately, not the whole health data were available and therefore, the health effects such as cough, lower respiratory symptoms, and the prevalence of bronchitis in children were not taken into account in the evaluation. That obviously underestimates the results obtained. It should also be emphasized that the population age-groups overlapped for the selected endpoints. For instance, assessing the attributable cases of hospital respiratory admissions among children under 15 years of age and hospital respiratory admissions among all children (all ages) would lead to an overestimation. Therefore, some age-group adjustments were performed (Table 1, column: population age-group *vs.* Table 2, column: population age-group in HIA).

The whole required health data were not presented in the report (CWO 2013) in the form that would allow their immediate use in the calculations. Therefore, for the endpoints connected with hospitalizations, the number of all hospitalized children (by relevant age-groups) was multiplied by the fraction of children hospitalized due to respiratory or cardiovascular reasons. Similarly, the data on postneonatal deaths were presented for infants aged 0–12 months, whereas the population age-group

Table 2 Annual impact of particulate matter (PM) on health of infants and children

Health outcome	Population age groups in HIA	Number of cases (population)	PM-attributable number of cases
Total postneonatal mortality including:	1 month-1 year	25	4
Postneonatal respiratory mortality		1	0
Postneonatal SIDS mortality		4	1
Mortality, all-cause	1–18 years	42	1
Incidence of asthma symptoms in asthmatic children[a]	5–18 years	56,733	5,201
Hospital respiratory admissions	<15 years	5,551	193
Hospital respiratory admissions	15–18 years	824	41
Hospital cardiovascular admissions	0–18 years	510	13

[a]Total person-days with asthma attacks
HIA Health Impact Assessment, *SIDS* sudden infant death syndrome

in the epidemiological studies was 1–12 month old. However, it was possible to derive a ratio of cases in first 1–12 months to 0–12 months (amounting to approx. 30 %) and adjust the data. Nonetheless, in case of sudden infant death syndrome (SIDS), the data were not adjusted, as the peak of its incidence occurs at 2–4 months of age (Kinney and Thach 2009). The use of the ratio would then definitely underestimate the result, so it was assumed that all four cases happened after the first month of life. The incidence of asthma symptoms in asthmatic children, as an endpoint, was calculated in two stages. Firstly, the number of asthmatic children in Warsaw was calculated as a product of all children in Warsaw and the percentage of diagnosed asthmatics (the average of age-groups: 6–7 and 13–14 years) in Warsaw (above 10 %) from a large Polish ECAP (Epidemiology of Allergic Diseases) study (Komorowski 2012). Secondly, the definition of the outcome regarding asthma symptoms (i.e. wheezing, shortness of breath, and asthma attacks) varied among the studies included in the meta-analysis (Weinmayr et al. 2010), from which the effect estimate was derived. In the present study the indicator for asthma symptoms were asthma attacks. However, due to the lack of such data for the Polish population, it was assumed that each asthmatic child, on average, suffers from three attacks a year. Such an assumption, based on the epidemiological data from other European countries, was adopted in a study by Künzli et al. (1999).

2.5 Number of Cases Caused by Air Pollution

The following formula was applied to obtain the number of cases caused by air pollution (n)[1]:

$$n = \frac{N}{1 + \frac{1}{(RR-1)\cdot\frac{E}{10}}}$$

where:

N – the total number of cases observed in the population of infants and children in Warsaw,

E – the exposure for infants and children in Warsaw (μg/m^3),

RR – relative risk selected from epidemiological studies.

3 Results

The mortality among infants and children was relatively low and occurred mostly in the postneonatal period (approx. 25 and 42 cases per year among infants aged 1–12 months and children

[1] For the derivation of this formula see: Kuschel et al. (2012).

Table 3 Probabilistic sensitivity analysis: particulate matter (PM) -attributable number of cases

Health outcome	Population age groups in HIA	PM-attributable number of cases		
		Median	5th percentile	95th percentile
Total postneonatal mortality	1 month-1 year	4	2	5
Postneonatal respiratory mortality		0	0	1
Postneonatal SIDS mortality		1	1	1
Morality all-cause	1–18 years	2	1	3
Incidence of asthma symptoms in asthmatic children[a]	5–18 years	5,173	1,786	8,203
Hospital respiratory admissions	<15 years	194	7	371
Hospital respiratory admissions	15–18 years	53	4	96
Hospital cardiovascular admissions	0–18 years	16	5	27

[a]Total person-days with asthma attacks
HIA Health Impact Assessment

aged 1–18 years). There were around 6,375 and 824 hospitalizations per year among children in Warsaw due to respiratory and cardiovascular problems, respectively. The incidence of asthma symptoms in children was high – assuming only three asthma attacks a year per asthmatic child – approx. 56,733 symptoms happened in a single year. The conducted HIA allowed to attribute some mortality/hospitalization cases to the particulate pollution. It was calculated that approx. 5 mortality cases were PM-attributable. Almost 5,201 asthma symptoms and 234 hospital respiratory admissions were caused by particulates. Hospitalizations due to cardiovascular problems related to the particulate pollution numbered 13. Table 2 presents the results – the total number of cases and the PM-attributable cases among all infants and children in Warsaw.

The results of the probabilistic sensitivity analysis: medians with percentile confidence intervals are depicted in Table 3.

4 Discussion

The aim of this study was to quantify the annual influence of air pollution on infants and children in the city of Warsaw in Poland. A summary of the estimates derived from the literature demonstrates a negative health influence, in particular on respiration. Overall, the health risk seems not be enhanced more than just a couple of percentage points, except for the risk related to postneonatal respiratory mortality which amounts to 21 %. However, the magnitude of the population exposed to this risk must be considered.

In case of infants and children, the absolute numbers connected with particulate-attributable deaths are not high, as children's mortality is generally low. However, the impact of PM on respiratory problems – asthmatic symptoms and hospitalizations – is considerable. It is worth emphasizing that the respiratory diseases are one of the most frequent reasons for hospital admissions among children. These diseases are also the most frequent cause, after postpartum complications, affecting the health status and requiring contact with health services.

The present study has limitations. The first problem concerns the transferability of the ERFs, derived from epidemiological studies, in which population of infants and children differed from the Polish one. The site-specific chemical composition of particulate matter also is different in various places. However, it seems that the use of meta-analysis of different studies for deriving the relative risks attenuates these problems. Finally, the assumption that the whole target population is exposed to the annual PM concentration may be easily criticized, since this idea fails to capture the relationship between the health of individuals in a population and the quality of air as measured at a fixed sampling point (e.g. Fisher et al. 2002). Nonetheless, the epidemiological studies have also been conducted among children who had different outdoor activity and who were exposed to different air quality.

This study followed the ‘at least approach’ and therefore only not-overlapping endpoints assessing the impact of particulates (and no other pollutants) on health were considered, so that no double-counting is present. The main reason for choosing PM as an indicator of air pollution is the credibility and recognition of the epidemiological studies, which the ERFs are based on. Although there is growing evidence for the impact of other pollutants on children’s health, a pollutant-by-pollutant assessment would grossly overestimate the impact.

Moreover, it was not possible to include in the assessment all the health effects found in the literature due to the lack of relevant health data for the target population. Generally speaking, the morbidity data in Poland are not directly available from health statistics. Even the prevalence of asthma among children in Warsaw is difficult to assess. According to a large national study ECAP (Komorowski 2012) asthma is diagnosed in 10 % of children undergoing medical examination, whereas self-diagnosed asthma in that study amounted to approx. 6 %. However, according to a report on the health status of Warsaw residents (CWO 2013), only 37 out of 1,000 children have been diagnosed with asthma. That means that respiratory problems are generally not well recognized and it is difficult to make an assessment based on these data. Finally, the relationship between the pollution and health outcomes for non-infant children is still understudied and relatively poorly understood (Beatty and Shimshack 2014). Summing up, it seems that the presented influence can be in reality much underestimated.

5 Conclusions

The current knowledge is sufficient to state that air pollution adversely affects human health and in particular infants and children, causing unnecessary loss, pain, and generating costs borne by the whole society. Quantification of this impact has become an increasingly important component in policy discussion. The present study demonstrates a significant impact of air pollution on infants and children in Warsaw, which is manifested primarily as a range of respiratory problems. Yet the most effective means of protecting people from environmental health threats is exposure prevention. Therefore, more attention should be paid for the integrated environmental health policy, with a focus on children and infants as priority.

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