Particulate Air Pollution and Its Impact on Health in Vilnius and Kaunas

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Summary. Particulate matter in outdoor air has a significant impact on health. Small particles, composed of a variety of organic and inorganic compounds, are inhaled deep into the respiratory tract. The mechanisms and outcomes are manifold, resulting mainly in cardiopulmonary diseases. The current study aimed to quantify the health effects of particulate pollutants in Vilnius and Kaunas.

Material and Methods. For risk estimation, the methodology of health impact assessment was employed. The exposure was defined as annual PM$_{2.5}$ levels for long-term exposure effects and daily PM$_{10}$ averages for short-term exposure effects. The baseline mortality/morbidity data were retrieved from health registers and exposure-response relationships from previous epidemiological studies. For health impact calculations, the WHO-developed tool AirQ was also applied.

Results. The annual average concentration of PM$_{2.5}$ was 11 µg/m$^3$ in Vilnius and 17.5 µg/m$^3$ in Kaunas. The exposure above the natural background corresponded annually to 263 (95% CI, 68–464) and 338 (95% CI, 86–605) premature deaths in Vilnius and Kaunas. This resulted in 3438 (95% CI, 905–5952) and 3693 (95% CI, 983–6322) years of life lost and in an average decrease in life expectancy of 0.43 (95% CI, 0.11–0.74) and 0.69 (95% CI, 0.18–1.19) years, respectively. In addition, 143 (95% CI, 86–200) and 129 (95% CI, 78–179) respiratory and 297 (95% CI, 169–338) cardiovascular hospitalizations per year could be expected in Vilnius and Kaunas, respectively.

Conclusions. There is substantial exposure to particulate matter in the main Lithuanian cities, which causes considerable adverse health effects. Traffic and domestic heating are considered locally the most important contributing factors to the degradation of air quality.

Introduction

Particulate matter (PM$_{10}$) is a mixture of small solid and liquid particles suspended in the air. Because of a very small size (less than 10 µm in diameter), they are inhaled deep into the respiratory tract. Moreover, the particles are bound with a number of toxic components, e.g., heavy metals and organic compounds, including polyaromatic hydrocarbons (PAHs), which contribute to the occurrence of adverse health effects.

Traditionally, particulates are divided into 3 groups according to the size. The largest coarse particles (PM$_{2.5-10}$, 2.5–10 µm) originate primarily from soil, road dust, and dirty industrial establishments. Smaller, i.e., fine, particles (PM$_{2.5}$) with a diameter of less than 2.5 µm come mainly from exhaust gases (transport), various combustion processes (boiler houses, local heating, and industry), and chemical reactions in the atmosphere. Local heating and particularly traffic are believed to be the most important sources of particulate air pollution in the main Lithuanian cities (1). Particulate matter passes through the upper respiratory tract (nose and throat) and reaches bronchioles, whereas fine particles get to alveoli. The smallest, i.e., ultrafine, particles (PM$_{<100}$ nm) are comparable in size to viruses and because of extremely small dimensions can penetrate directly into the bloodstream.

Particles with the abovementioned components (heavy metals and PAHs) are able to provoke prooxidative and proinflammatory processes in the airway cells and cause inflammatory changes inducing the activation of redox mechanisms and oxidative stress (2–4). Moreover, the accumulation of active oxygen species can lead to a dysfunction of the lung epithelial lining and promote lipid peroxidation in cell membranes, causing damage to the respiratory mucous membranes (5, 6). Due to chronic airway inflammation, the fibrotic processes, chronic obstructive pulmonary disease, severe asthma, allergic expressions, and even cancer may develop in exposure with time (7). Furthermore, the effects of fine particles deposited in the pulmonary tree can directly stimulate lung nerve reflexes via irritant receptors and consequently alter the autonomic nervous system balance (i.e., change the activities of the parasympathetic nervous system and/or the sympathetic nervous system) (2). Through these mechanisms, particles can affect the heart rate and cause...
cardiac arrhythmias. Moreover, the effects such as vasoconstriction, endothelial dysfunction, and increased blood pressure have also been reported (8).

Ultrafine particles found in particulate matter can be transferred through the blood circulation system due to their very small size, can cause systemic inflammation and malfunction of the cardiovascular system, and can contribute to the progression of atherosclerosis (4). In addition, ultrafine particles have been found to intensify the coagulation process and worsen cardiovascular insufficiency (2). This in turn may increase the risk of myocardial infarction, hypertrophy, and mortality.

In addition to toxicity, the exposure time and the concentration of particles are also important determinants of health effects. Negative effects can appear as the consequence of short-term high or long-term modest exposures. High concentrations of fine particles (>50 μg/m³) often occur in the event of adverse weather conditions (inversion), where the dispersion of pollutants is limited. However, spring road dust and large-scale biomass burning (9, 10) can induce very high pollution levels as well. Such high, but short-term pollution episodes may cause very different symptoms from eye irritation to exacerbations of chronic respiratory and cardiovascular diseases in humans. Moreover, long-term exposure to fine particles can significantly increase morbidity and mortality due to cardiopulmonary diseases, and life expectancy can be reduced by a number of years (11–13). The effects have been shown to emerge even at concentrations lower than the current limit values in the European Union (4, 14). As the levels of particulate matter have been found to be quite large in the main Lithuanian cities (15), there is a high probability that most of the health effects of air pollution are caused by particulates and specifically those related to toxic substances. Based on that, the concentrations of PM₁₀ and PM₂.₅ have also been seen as the indicators of hazardous air pollution in the urban areas of Lithuania (16).

A health impact assessment as an option for risk analysis is a combination of different procedures, methods, and tools by which a policy, program, or project may be evaluated on the basis of its potential effects on the health of a population and the distribution of those effects (17). In the health impact assessment of air pollution, often the excess cases are calculated as an increase or a decrease in mortality/morbidity compared with the baseline incidences resulting from air pollution exposure (PM concentration), using the relationship between exposure and mortality/morbidity reported in previous epidemiological studies. This concept of health impact assessment has been suggested internationally by the World Health Organization (WHO), American Heart Association, etc. and has been widely applied for assessing the health impacts of particulate matter, especially PM₂.₅ (18, 19).

In Lithuania, the environmental and health monitoring is developed at an adequate level; however, integrated analyses and health impact assessments that could be used for tailoring locally suitable policy measures are still scarce (15, 20). Therefore, the current health impact assessment aimed to determine the levels and the number of persons exposed to particulate air pollution in Vilnius and Kaunas and to assess its impact on morbidity and mortality cases, years of life lost, and decrease in life expectancy.

**Material and Methods**

For the health impact assessment, the data on the population structure, current mortality and morbidity rates in different age groups, exposure to air pollution, as well as exposure–response (E–R) relationships from epidemiological studies were obtained. The data on the structure of the population in different age groups, which were necessary for the implementation of the life-table methods for calculating life expectancy and years of life lost, were extracted from Statistics Lithuania in Vilnius and Kaunas in 2008. The data on baseline total mortality (A00–Y98) and cardiovascular (I00–I99) as well as respiratory (J00–J99) hospitalizations in 2008 were retrieved from the Lithuanian Health Information Centre databases.

The long-term exposure to particulate pollution was defined as the annual average concentration of PM₂.₅ in ambient air in Žirmūnai monitoring station in Vilnius and Petrašiūnai station in Kaunas in 2007–2008. The representativeness of the centrally located monitoring station as the population average exposure was validated in Vilnius. For that, the annual average concentration of PM₂.₅ during the same period was modeled in 250×250-m grids with the dispersion model ADMS-Urban based on emissions (traffic, local heating, district heating, industrial plants, background, etc.) and meteorological parameters. Subsequently, the population average concentrations were calculated based on pollution levels in neighborhoods and number of inhabitants living there. The obtained concentration was compared with the actual measured levels in Žirmūnai monitoring station during the same period. Human exposure levels were based on the place of residence, given that a person spent the largest part of the day there. The premature mortality effects were calculated beyond the natural background levels of fine particles among persons aged 30 years and more (first, few effects have been seen below these levels; second, no local actions can be done to reduce the natural background). As fine particles have not been measured in background areas in Lithuania, the levels from the other Baltic State, Estonia (4.8 μg/m³ in
The exposure was expressed as the daily average concentrations of PM$_{10}$ measured in Žirmūnai, Savanorių Avenue, Senamiestis, and Lazdynai stations in Vilnius and in Petrašiūnai station in Kaunas.

The relationships among mortality, morbidity, particulate matter, and fine particles originate from previous epidemiological studies. To quantify the effects of fine particles on mortality, the broadly employed relative risk (RR) of 1.06 associated with a 10-μg/m$^3$ increase in PM$_{2.5}$ from the American Cancer Society study was implemented as the exposure-response relationship (22). For the calculation of respiratory hospitalizations due to short-term air pollution episodes, the RR of 1.0114 associated with a 10-μg/m$^3$ increase in PM$_{10}$ as the European wide metacoeficient was used (23). The RR for cardiovascular hospitalizations (RR of 1.0073 per 10-μg/m$^3$ increase of PM$_{10}$) was calculated as a weighted average based on the occurrence of cardiac and cerebrovascular admissions with RRs from COMEAP meta-analysis (24).

The cases of premature deaths were calculated with the following equation:

$$\Delta Y = (Y_0 \times \text{pop}) \times (e^{\beta X} - 1),$$

where $Y_0$ is the baseline mortality rate; pop, the number of exposed persons; $\beta$, the exposure-response relationship (relative risk); and $X$, the estimated excess exposure.

The health effects as years of life lost were estimated with the life-table method in which air pollution-affected life expectancy was compared with the expected hypothetical ideal life expectancy. For the calculations, the WHO-developed software AirQ 2.2.3 was applied. The loss per premature death was calculated as a deviation between the total years of life lost (during the first year of simulation) and the number of premature death cases. The number of hospitalizations due to particulate matter was found using the same software AirQ with an additional module based on the occurrence of different exposure levels.

Results

In total, 555 733 and 355 586 residents were registered living in Vilnius and Kaunas in 2008, respectively. The baseline mortality among persons aged 30 years and more was 7180 cases in Vilnius and 4594 cases in Kaunas. There were expected 10 996 respiratory hospitalizations in Vilnius and 7037 in Kaunas as well as 24 936 cardiovascular hospitalizations in Vilnius and 15 955 in Kaunas.

The annual average concentration of fine particles in Žirmūnai station, Vilnius, and in Petrašiūnai station, Kaunas, was 11 μg/m$^3$ and 17.5 μg/m$^3$, respectively. The modeled annual population weighted average concentration of particulate matter in Vilnius was 29.2 μg/m$^3$ (Fig.). At the same time, the annual concentration of PM$_{10}$ in Žirmūnai station...
was 32 μg/m³ in 2007 and 27 μg/m³ in 2008. This indicates that the monitoring station should represent well the population's exposure to particulate matter in Vilnius. The daily average concentrations of PM$_{10}$ ranged from 2 to 154 μg/m³ in Vilnius and from 4 to 154 μg/m³ in Kaunas. However, the concentrations in the range of 10–40 μg/m³ dominated.

According to the AirQ estimates, exposure to particulate air pollution among the inhabitants of these 2 cities could result in 601 (95% CI, 154–1069) premature deaths a year, which could result in 7131 (95% CI, 1888–12 274) years of life lost per year. The decrease of life expectancy was predicted to be 0.53 years (95% CI, 0.14–0.92) on the average. However, the loss per premature death cases was much greater (11.9 years), which refers to the concentration of health damage to affected persons. The major susceptible groups could primarily be people with chronic cardiovascular, respiratory, or other diseases, the elderly, etc. As it turned out, these groups may be living several years less because of high air pollution levels. In addition, 272 (95% CI, 165–379) respiratory and 564 (95% CI, 357–717) cardiovascular hospitalizations were expected. The effects were relatively greater in Kaunas due to greater exposure to particulate air pollution (Table).

**Discussion**

The analysis has shown that air quality affects health and life quality of all residents of Vilnius and Kaunas. Moreover, it appeared that the health loss was considerably higher in the affected groups of people than among the rest of the population. If the decline in life expectancy, on average 0.53 years, seems more acceptable, the mean loss of 11.9 years among affected persons seems exceptionally important.

For the prevalence and development of health effects, both short-term exposure to particulate matter (PM$_{10}$) and long-term exposure to fine particles (PM$_{2.5}$) are essential. On the one hand, it is believed that chronic effects are induced by long-term exposure; the disease can be induced by very high short-term levels of pollution. On the other hand, if a person has already developed a chronic disease (due to various reasons), very high levels of pollution could also lead to premature mortality or hospitalization.

However, questions may arise if the relationships between air pollution levels and health effects reported in international studies are directly transferable to the local population structure as the sources of pollutants and the composition of fine particles may differ. Moreover, it has been shown that the relationships between exposure and health effects vary in different studies (4). Although we used the most consistent relationship, the bias is possible; the previous discussion within the Clean Air for Europe (CAFÉ) program has confirmed the applicability of the estimated (19). Similarly, one may question whether the study results may overestimate the real situation, because when compared with the limit, and target values, the pollution levels are not so high. As the overall mortality rate in Lithuania is high, it amplifies the results in absolute numbers in the current risk analysis. However, the results may also indicate that there can be a higher proportion of people susceptible to air pollution. This bias has obviously come out in such risk assessments in Russia (25), where air quality is bad, but a very high mortality rate is largely caused by poor socioeconomic situation and adverse health behavior (e.g., high alcohol consumption). Thus, when the baseline mortality is very high, the use of the far-spread relationships can result in the overestimation of the effects of air pollution. Moreover, since baseline cardiovascular hospital admissions are initially high in Lithuania, the estimated effects due to particulate air pollution are higher compared with respiratory hospitalizations.

Another important issue largely affecting the results is that health effects were calculated for PM levels above the natural background. Fine particles have not been measured in background areas in Lithuania. During the study period, the average of background levels in 3 Estonian measuring stations was 4.8 μg/m³ (21), and the annual concentration in nearby areas of Finland were 4–7 μg/m³ (26). There have been some estimations that the annual average level in the Lithuanian countryside (as the natural background) could be 7.5 μg/m³ (27). In the current study, the natural background levels from Estonia were retrieved, as there might have been a crucial underestimated in health effects due to an earlier overestimation of the background level in Lithuania. For instance, if the effects had been calculated with the higher background value, the health consequences would have been by 42% smaller in Vilnius and by 20% smaller in Kaunas. Moreover, the ratio between PM$_{2.5}$ and PM$_{10}$ was

<table>
<thead>
<tr>
<th>No. of Premature Deaths a Year (95% CI)</th>
<th>Years of Life Lost due to Deaths During the First Year of Simulation (95% CI)</th>
<th>No. of Hospitalizations a Year (95% CI)</th>
<th>Decrease in Life Expectancy, Years (95% CI)</th>
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<tbody>
<tr>
<td>Vilnius 263 (68–464)</td>
<td>3438 (905–5952)</td>
<td>Respiratory 143 (87–200) Cardiovascular 297 (188–377)</td>
<td>0.43 (0.11–0.74)</td>
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<td>Kaunas 338 (86–605)</td>
<td>3693 (983–6322)</td>
<td>Respiratory 129 (78–179) Cardiovascular 267 (169–340)</td>
<td>0.69 (0.18–1.19)</td>
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*Table: Quantification of the Main Health Burden and Decrease in Life Expectancy Due to Particulate Air Pollution in Vilnius and Kaunas*
relatively low during 2007–2008. In the later period (2009–2011), the ratio was higher, and the annual concentrations of PM$_{2.5}$ were higher (28). Thus, the health effects in Vilnius might be somewhat underestimated due to relatively low levels of PM$_{2.5}$ measured in 2007–2008.

Despite the limitations, the health impact assessment has a number of advantages such as the speed (quick results can be given to the general public and decision makers) and relatively small amount of necessary resources (e.g., epidemiological studies of the long-term impact are very time-consuming and expensive). In many cases, the health impact assessment could be the first phase of the studies, which will give stakeholders an overview of the extent of the problem that could be followed with more specific research.

If we compare the extent of the effects in Lithuania with other European countries, the average loss per resident is somewhat below the European average of 8.6 months reported in the previous analyses (29). Furthermore, comparing the exposure to particulate matter in outdoor air with other European countries, most people in Lithuanian cities are exposed to PM$_{10}$ levels that are similar to the European countries with average pollution (30). However, these levels of particles are above the WHO's guidelines for air quality (14). The CAFE cost benefit analysis estimated that there might have been 2190 premature deaths in 2000 due to particulate air pollution in Lithuania compared with our 601 in Vilnius and Kaunas in 2007–2008 (28% of the population) (31). In 2006, the WHO estimated that a decrease in life expectancy due to air pollution would be about 0.5 years in Lithuania in 2010 (19). Health impact assessment analyses in other Baltic States, namely in Estonia, have shown somewhat similar effects: a decrease in life expectancy by 0.64 years in Tallinn (13) and by 0.95, 0.68, 0.51, and 0.35 years in Pärnu, Tartu, Narva, and Kohila-Järve, respectively (32). The relative effects were close to the Estonian results in Kaunas due to the higher exposure to particulate pollution. The main reasons for higher concentrations in Kaunas are higher proportion of industry as well as the influence of topography on dispersion conditions, etc. In the analysis by Boldo et al. (2006) in 23 cities of the Apheis project, the gain in life expectancy, if the PM$_{2.5}$ annual levels did not exceed 15 μg/m$^3$, was from only a few months in most cities to close to 2 years in Bucharest and Tel Aviv (33). Besides premature mortality and hospitalizations, adverse effects could also be from cancer and several other morbidity effects (34). Moreover, as there are very few epidemiological studies on symptoms that need ambulatory care (main problems stem from data availability and reliability), these could not be included in the risk assessment. Epidemiological studies with nitrogen dioxide, another traffic-induced pollutant, carried out in Kaunas showed effects on myocardial infarction and respiratory symptoms; however, in case of respiratory symptoms, the effects were not statistically significant (35, 36).

**Conclusions**

In total, particulate matter in outdoor air in Vilnius and Kaunas causes around 600 premature deaths a year, involving about 7000 years of life lost each year. The average decrease in life expectancy per premature death case is almost 12 years on average. For the total population, these years of life lost mean a shorter life expectancy by about 5 months in Vilnius and 8 months in Kaunas. Besides premature mortality, 272 cases of hospitalization due to cardiovascular disease and 564 cases due to cardiovascular complaints can be predicted annually.

The study results indicate that air pollution is an important public health concern in Lithuania, and thus, specific policy measures and their effective enforcement to reduce the effects on morbidity and premature deaths are needed. Some of the possible interventions for reducing the exposures include cutting down on emissions from traffic, local heating, etc., creating better environment for pedestrians and cyclists as well as informing susceptible groups about more polluted areas and air pollution episodes.

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**Statement of Conflict of Interest**

The authors state no conflict of interest.

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