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Disability-Adjusted Life Years in the Assessment of Health Effects of Traffic-Related Air Pollution

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Abstract

Traffic-related air pollutants have an impact on human health and have been recognized as one of the main stressors that cause mortality and morbidity in urban areas. Research confirms that citizens living in the vicinity of main roads are strongly exposed to high concentrations of numerous air pollutants. In the present study the measurements of traffic-related parameters such as density, velocity, and structure were performed for cross-sections of selected street canyons in Warsaw, the capital city of Poland. In addition, the results of the general traffic measurements were used to describe the number of cars crossing the border of the city. Vehicle emissions of PM_{10} were calculated for the whole city area and changes of the PM_{10} concentration were modeled to present the exposure to this pollutant that could be attributable to traffic. The principles of the environmental burden of disease (EBD) were used. The assessment of the impact of traffic-related air pollutants on human health was made. The results, presented in disability-adjusted life years (DALY), were based on the outcomes of the study conducted in 2008–2012 in Warsaw, one the most congested agglomerations in Europe, and included the health damage effect of the exposure to high concentrations of air pollutants. DALY calculations were performed in accordance to the methodologies used in renowned international scientific research on EBD.

Keywords

Environmental burden of disease • Health damage • Particulate matter • Traffic congestion • Urban air pollution

1 Introduction

Road transport plays a vital role in air pollution emissions, especially in large cities. According to the 2011 data of European Environment Agency (EEA), transport is responsible for emissions of

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17 % of particulate matter PM_{10} and 32 % of nitrogen oxides in the European Union. An adverse influence of high air pollution on human health, especially for the particulate matter PM_{10} and $PM_{2.5}$, is known (Badyda et al. 2013a; Pope et al. 1995, 2002; Krewski et al. 2000). Moreover, the World Health Organization has not determined a safe level of concentrations of particulate matter yet (WHO 2006). This means that an increase of particulate matter concentration by each μg/m^3 causes a specific health effect. According to the research by Lim et al. (2012), approximately 430,000 people died prematurely in Europe due to air pollution in 2010. The assessment of health effects of exposure of a population to particulate matter $PM_{2.5}$ takes into account the upper and lower respiratory infections, lung cancers, ischemic heart disease, cerebrovascular disease, and chronic obstructive pulmonary disease (COPD). Thus, research results suggest that traffic-related emissions are partly responsible for early deaths as a result of the abovementioned diseases

Pope et al. (2009) have determined that a positive health effect that could be obtained by reducing the concentrations of $PM_{2.5}$. Reductions of $PM_{2.5}$ over 5 years by 10 μg/m^3 increase life expectancy by 3 years. The methodology of the study took into account the change in mortality due to lung cancer and COPD of the whole population.

Symptoms of disease connected with increased air pollution are apparent in the studies on admissions to hospitals due to cardiovascular problems (e.g., imminent myocardial infarction). Daily exposure to high pollution contributes, particularly, to cardiovascular diseases, thereby increasing the risk of anemia, heart failure, or arrhythmia (Autrup 2010). Moreover, there is evidence of a relationship between increased concentration of particulate matter in the outdoor air and a greater risk of myocardial ischemia or infarction, arrhythmia, heart failure, peripheral arterial stroke, and sudden death (Franchini and Mannucci 2012; Nelin et al. 2012; Zanobetti et al. 2011).

To determine the influence of air pollution on human health, numerous studies have been conducted and various models have been elaborated (Laden et al. 2006; Tainio et al. 2005; Hoek et al. 2002), which include the following:

- emission volumes from transportation sources,
- pollution dispersion in the atmosphere,
- impact of pollution increase on human health,
- assessment of health damage in a population.

The Environmental Burden of Disease (EBD) is a methodology that enables to assess the influence of air pollution on health damage on the basis of emission volume. A tool used to conduct the EBD analysis is the GaBi5 software which implements the models of the Life Cycle Impact Assessment (LCIA). In the present paper we use one such LCIA methodology, called ReCiPe, to assess health damage and quality of life of a big city inhabitants living in the vicinity of busy traffic routes.

2 Methods

The study consisted of the measurement and calculation stages. The first one included measurements of traffic parameters and air pollution concentrations in seven chosen locations in Warsaw, the capital city of Poland. The measurement sections with heavy traffic and congestions were selected with the premise that the slowness of traffic allows a more reliable estimation the identification of vehicle types and their ecological structure (engine types, ranges of cubic capacity, emission standards, etc.). Measurements of traffic parameters were made around the clock over 1 week in June and October of 2010.

2.1 Measurements of Traffic Parameters and Pollution Concentration

The measurement of traffic parameters was conducted using an NC-200 analyzer (Vaisala; Vantaa, Finland). The analyzer was placed in the middle of each lane and registered (using magnetic resistance) the passage of each vehicle, including its speed and length. Traffic density was determined taking into consideration the division into four categories of vehicles: passenger cars, light goods vehicles, small buses and vans, and large buses and large goods vehicles.

Measurements of air pollution (carbon monoxide, nitrogen oxides, volatile organic compounds, and particulate matter PM_{10}) were conducted with a mobile monitoring station Airpointer™ (MLU, Wiener Neudorf, Austria). PM_{10} concentration was measured by nephelometry and that of nitrogen oxides by chemiluminescence. Apart from the models linked to particulate matter, other models being part of the ReCiPe methodology were used, according to which 21 % of the emitted nitrogen oxides are created from the particulate matter PM_{10} (Goedkoop et al. 2008).

2.2 Calculations of Traffic Emission and Its Intensity

The results denoting traffic density, average speed, and types of vehicles were used to model emissions of pollution, which allowed determining the emission concentration (Chłopek 1999). A unique model of traffic-related emissions for vehicles in Warsaw was created, taking into consideration the ecological structure of the traffic. The results obtained on the basis of this model were verified by live measurements of PM_{10} at the monitoring stations. Moreover, the 2013 traffic forecast, based on the general traffic measurements conducted in Warsaw, was used as surrogate of the volume of PM_{10} emissions for the whole road network in Warsaw. These results were then employed to assess the impact of the whole stream of traffic-related pollution (PM_{10} and nitrogen oxides emissions over the whole year) on health damage of city inhabitants. Traffic modeling was made using EMME3 software (INRO, Montréal, QC). The results covered the 24-h vehicle traffic in Warsaw expressed in vehicle-kilometres and included:

- four categories of vehicles as outlined above;
- 19 ranges of speed (starting with the 0–10 km/h, followed by 5 km/h increases up to 95 km/h and above);
- 5 time scales: rush hours twice (an hour in the morning and afternoon each), time around the rush hours (when the traffic density remains high), time between the rush hours, and night time.

2.3 Assessment of Health Damage to People Living in the Vicinity of Heavy Traffic

Data from the emission model were used to calculate the volume of health damage in relation to the city population. For this purpose, the GaBi5 software was used, employing so-called models of substance fate, which determine the physical and chemical processes occurring after the substance emission to the atmosphere. The following processes were taken into account: creation, migration, transformations, and absorption of pollution in the atmosphere. On the basis of results of numerous epidemic studies on the impact of pollution on human health, the percentage of population having a given health effect connected with increased concentration of pollutants was determined. The last stage was the assessment of the volume of health damage expressed as the population health index DALY (disability-adjusted life years), which is a sum of potential years of life lost due to early death and the years of life with a specific disability, e.g., COPD.

3 Results and Discussion

Increases in the traffic density during the morning and afternoon rush hours cause a decrease in the average speed of vehicles, thereby generating traffic congestion and contributing to greater emissions of harmful substances. Therefore, specificity of changes of traffic parameters at different times of day was taken into consideration when modeling emissions. During the rush hours (lasting in total 2 h) in the analyzed road network, the number of vehicle-kilometres accounts for ca 25 % of the total 24-h transport activity which stands at ca 12.3 million of vehicle-kilometres over 24 h. Vehicles in the morning rush hour drive at the average speed of 28.7 km/h. The average speed at the time around the rush hours rises to 35.3 km/h and between the rush hours to 36.9 km/h. The highest speed is observed at night (40.9 km/h).

The influence of the average speed on pollution emissions, as assessed from the level of

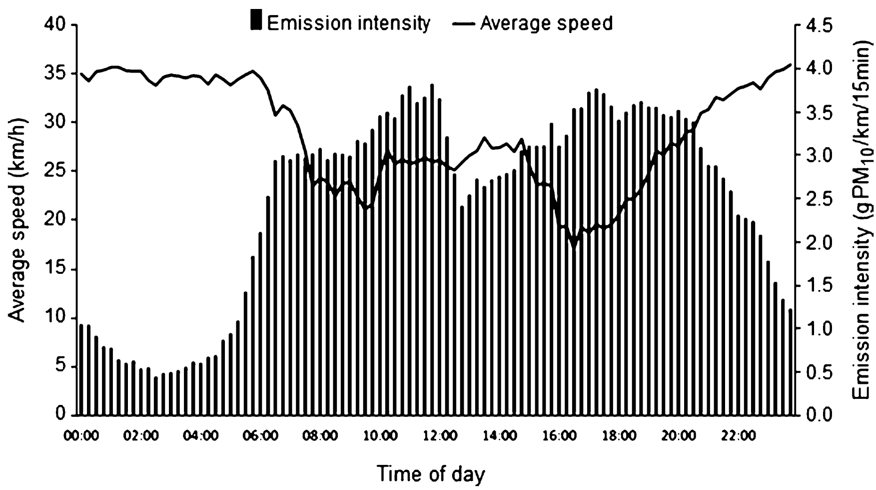

Fig. 1 Average 24-h characteristics of PM_{10} emission in a measurement section in Warsaw

Table 1 Emissions of particulate matter PM_{10} in kg per year, calculations for 2013

Time of day	Passenger cars	Light goods vehicles	Small buses and vans	Large buses and trucks
Morning rush hour – 1 h	10,926	3,898	2,457	6,066
Afternoon rush hour – 1 h	10,245	3,718	2,285	5,641
Around the rush hours – 5 h	137,558	46,566	25,909	63,959
Between the rush hours – 8 h	217,074	72,697	39,374	97,198
Night – 9 h	54,986	18,311	9,157	22,604

Table 2 Emissions of nitrogen oxides in kg per year, calculations for 2013

Time of day	Passenger cars	Light foods vehicles	Small buses and vans	Large buses and trucks
Morning rush hour – 1 h	410,489	57,603	62,535	154,374
Afternoon rush hour – 1 h	378,622	54,766	58,136	143,515
Around the rush hours – 5 h	4,783,864	666,407	683,050	1,686,184
Between the rush hours – 8 h	7,424,412	1,032,443	1,048,146	2,587,463
Night – 9 h	1,802,020	252,714	254,819	629,050

PM_{10}, is illustrated in Fig. 1. An increase in vehicle traffic in the streets generates a decrease in the traffic speed, resulting in a greater consumption of fuel and thereby greater air pollution emission.

The modeling of pollution emission was made for particular times of day and types of vehicles (Tables 1 and 2). The results show that, assuming that the forecast data of traffic streams for 2013 are true, road traffic emitted approximately 850 Mg of PM_{10} and 24 Gg of nitrogen oxides in the whole road network in Warsaw. The largest share in the emissions belongs to passenger cars which emitted 50.6 % of the total volume of PM_{10} and 61.2 % of the total volume of nitrogen oxides. The emission was calculated only for the combustion of the fuel phase, which is a part of the life cycle of vehicles. However, in this process the biggest part of harmful to health pollutions are emitted (Chłopek and Lasocki 2013). Calculations show that the emission is greatest during the 8-h time between the rush hours. It is also worth noting that between the rush hours and around them the speed of vehicles increases only by ca 6–7 km/h, so that vehicles still do not drive optimal conditions, which contributes to the relatively significant emission of pollution.

The calculations described above were employed to assess the volume of health damage to the population using the ReCiPe model of LCIA methodology. The assumed index of health effects is the DALY index, which determines the number of years of life adjusted with disability. Results in the DALY unit should be interpreted as a total loss of a given number of years of life in full health due to a given population.

The ReCiPe model shows that the emission of 1 kg of PM_{10} causes a loss of health of 0.00026 DALY, while that of 1 kg of nitrogen oxides is connected with a deterioration of life quality at the level of 0.000057 DALY. Assuming the level of PM_{10} emission from the transport sector in Warsaw at the above mentioned level of 850 Mg per year, there is a loss of life years adjusted with disability of 221 DALY. In turn, annual emission of 24 Gg NO_x is connected with a loss of 1383 DALY. Therefore, annual loss for the whole population of 1.7 million citizens of Warsaw due to exposure to traffic-related emissions of PM_{10} and NO_x would approximate 1604 DALY. A limitation of the vehicle speed in the road network, which contributes to the creation of traffic congestion, has a significant bearing on the emission level. It also needs to be pointed out that the greatest impact on the emissions of both particulate matter (49 %) and nitrogen oxides (61 %) have to passenger cars, whose share in the total traffic density stands at almost 89 %. A significant part of emissions (34 % for PM_{10} and 31 % for NO_x) is caused by buses, which however have only a 3 % share in the whole road traffic in the road network of the city.

4 Conclusions

The presented results of the volume of health damage in the population of Warsaw show that traffic-related air pollution with PM_{10} and nitrogen oxides contributes to the annual loss of more than 1600 DALY. Health damage is caused mostly by higher morbidity due to chronic respiratory diseases (Badyda et al. 2013b). It is worth noting that the 2009 WHO estimates for all urban areas in Poland showed that all particulate matter emission sources result in the annual loss of 86400 DALY. Thus, the share of pollution emitted from transportation in Warsaw alone accounts for almost 2 % of the health damage calculated for the whole country and all emission sources. The calculated health damage comes only from local road transport emission, but air pollution can travel long distance, so that the total DALY including other sources of pollution (energy, industry, and road transport in other urban areas) would be higher (Juda-Rezler et al. 2011).

The estimation of volumes of health damage caused by traffic-related pollution, conducted with the methodology being widely employed to analyze life cycle, yielded satisfactory results. However, the models used in the present study do not allow determining the exact kind of health damage. That is a limitation of the LCIA method, which requires making numerous assumptions and simplifications due to imperfection of input data to the model. Nevertheless, the results seemed to assess well the influence of traffic-related air pollution on the health condition of the analyzed population. It is estimated that one per 10,000 Warsaw's citizens loses 9.5 years of healthy life over his entire life due to traffic-related emissions, as a result of chronic diseases and potentially early death.

Conflicts of Interest The authors declare no conflicts of interest in relation to this article.

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