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# Burden of disease caused by local transport in Warsaw, Poland

Marko Tainio [a,b,*]

[a] UKCRC Centre for Diet and Activity Research (CEDAR), MRC Epidemiology Unit, University of Cambridge School of Clinical Medicine, Box 285 Institute of Metabolic Science, Cambridge Biomedical Campus, Cambridge CB2 0QQ, United Kingdom
[b] Systems Research Institute, Polish Academy of Sciences, Newelska 6, 01-447 Warsaw, Poland

A R T I C L E I N F O

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A B S T R A C T

Transport is a major source of air pollution, noise, injuries and physical activity in the urban environment. The quantification of the health risks and benefits arising from these factors would provide useful information for the planning of cost-effective mitigation actions. In this study we quantified the burden of disease caused by local transport in the city of Warsaw, Poland. The disability-adjusted life-years (DALYs) were estimated for transport related air pollution (particulate matter (PM), nitrogen oxides ($NO_x$), sulfur dioxide ($SO_2$), benzo[a]pyrene (BaP), cadmium, lead and nickel), noise, injuries and physical activity. Exposure to these factors was based on local and international data, and the exposure-response functions (ERFs) were based on published reviews and recommendations. The uncertainties were quantified and propagated with the Monte Carlo method. Local transport generated air pollution, noise and injuries were estimated to cause approximately 58,000 DALYs in the study area. From this burden 44% was due to air pollution and 46% due to noise. Transport related physical activity was estimated to cause a health benefit of 17,000 DALYs. Main quantified uncertainties were related to disability weight for the annoyance (due to noise) and to the ERFs for fine particulate matter ($PM_{2.5}$) air pollution and walking. The results indicate that the health burden of transport could be mitigated by reducing motorized transport, which causes air pollution and noise, and by encouraging walking and cycling in the study area.



## 1. Introduction

Transport is a major source of air pollution, noise, injuries, physical activity and other factors which have a direct impact on population health. In the Global Burden of Disease Study (GBD) 2010 fine particulate matter ($PM_{2.5}$) air pollution, physical inactivity and lead (Pb) were the ninth, 10th and 25th most important risk factors, respectively (Lim et al., 2012). Road injuries were the 10th most important cause of death in the same study (Vos et al., 2012). In the further analyses of the GBD 2010 data, the Global Safety facility group concluded that motorized road transport deaths exceed those from the diseases such as HIV, tuberculosis or malaria, in the global level (Bhalla et al., 2014). In the "*European Perspectives on Environmental Burden of Disease*" (EBODE) study it was calculated that 80% of the environmental health burden in six European countries was due to $PM_{2.5}$, noise, lead and benzene (Hänninen and Knol, 2011; Hanninen et al., 2014). Transport is an important source of all these factors.

The connection between transport and health through different factors has been recognized in several reviews, reports and commentaries (De Nazelle et al., 2011; Dora, 1999; Hyder et al., 2006; Kjellstrom et al., 2003; McCarthy et al., 2010; Thomson et al., 2008). For example, Dora (1999) commented that transport policies have important health consequences through air pollution, noise, injuries, climate change and by providing a safe environment for physical activity. The review of De Nazelle et al., (2011) built a conceptual model between active travel policies and health, and recognized that these are connected by air pollution, greenhouse gases, noise, heat, ultraviolet (UV) radiation, traffic hazards, physical activity, and other mediators.

Although the linkages between transport and health through different factors have been recognized, relatively few studies have quantified this relationship by taking into account several factors. For example, the aforementioned Global Safety facility group quantified the health effects of transport through injuries and $PM_{2.5}$ air pollution alone (Bhalla et al., 2014). Some active transport studies have

* Tel.: +44 1223 746887.
*E-mail address:* mkt27@medschl.cam.ac.uk

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combined the health effects of air pollution, injuries and physical activity in urban and national levels (Macmillan et al., 2014; Rojas-Rueda et al., 2011; Woodcock et al., 2014, 2013, 2009). The most comprehensive health assessment that we are aware of is the Swedish Health Impact Assessment (HIA) of road transport that estimated the health effects of transport-related physical activity, air pollution, injuries, noise and climate change (Kjellstrom et al., 2008). Also some economic analyses, such as Cravioto et al., (2013) study from Mexico, have involved several factors in one assessment.

Most of the papers mentioned in the previous paragraph have assessed the health burden due to transport in national or international level. Many of the transport related factors, such as noise, injuries and physical activity, are local by nature, meaning that the health effects are felt near the source. Also, a significant part of the exposure to air pollution can occur near the roads in urban environments (Greco et al., 2007; Tainio et al., 2014). This indicates that local decision making has the potential to mitigate the adverse health effects caused by these factors; possibly more than national or international mitigation actions. To engage in such mitigation activities local decision makers require data on the magnitude of the health effects caused by transport, along with the relative importance of different factors to plan and prioritize the mitigation actions.

In this study the health effects of local transport for the local population are estimated for the city of Warsaw, Poland. The specific aims are: (i) to assess disability-adjusted life-years (DALY) caused by transport related air pollution, noise, injury and physical activity, and (ii) to assess DALYs for different air pollutants (particulate matter (PM), nitrogen oxides ($NO_x$), sulfur dioxide ($SO_2$), benzo[a]pyrene (BaP), cadmium, lead and nickel). The uncertainties of the main input variables are defined and the impact of that uncertainty to the model result is tested with sensitivity analyses.

## 2. Methods

### 2.1. Overview and the study area

The burden of disease due to local transport was estimated by modeling the exposure to transport related air pollution, noise, injuries and physical activity, and by calculating the changes in the background burden with and without these factors. Thus, the business as usual scenario was compared to the counterfactual scenario where the exposure to the transport fraction of these factors is zero. Air pollution, noise and injuries were estimated to cause negative health effects, expressed as DALYs. Physical activity due to active transport (walking and cycling) was estimated to improve health, represented as negative DALYs, i.e., reduction in disease burden. The main data sources are listed in Table S1 (Supplementary material).

The study area consisted of the administrative area of the city of Warsaw, Poland. In 2010, Warsaw had approximately 1.7 million inhabitants with an average population density of 3287 inhabitants/$km^2$ (Statistical Office in Warsaw, 2012). Inside the city border approximately 2.6 million trips are made every 24-h period (Capital City of Warsaw, 2010). Of all these trips, 22% are made by walking, 23% by car, 55% by public transport, and 1% by other modes of transport (Capital City of Warsaw, 2010). According to TomTom (2012) European Congestion index Warsaw was the most congested city in the Europe.

### 2.2. DALY and the background burden data

In our study the health effects of transport are illustrated using DALYs. The DALY method has been developed in the Global Burden of Disease studies (Harvard School of Public Health et al., 1996; Murray and Lopez, 1997; Murray, 1994) and it has been used in several studies to combine and illustrate the health effects (Hanninen et al., 2014; Kjellstrom et al., 2008; Woodcock et al., 2014, 2013, 2009). DALYs have two components: years of life lost due to premature mortality or fatality (YLLs) and years lived disabled or injured (YLDs). The YLLs are calculated by comparing the age of the deceased person to the estimated life expectancy expected in a person of the same age and gender. YLDs are calculated by multiplying the number of diseases or injuries with the disability weight (DW) of that disease or injury and the duration ($D$) of the disease or injury. With lifelong diseases and injuries the duration used is the remaining life expectancy of the person.

The accurate calculation of DALYs depends on the availability of data, knowledge of the relationships between the exposure and the health outcomes, and other variables. In this study methods used in previous burden of disease studies (Hänninen and Knol, 2011; Hanninen et al., 2014), or recommended in the World Health Organization (2011) guidelines (Fewtrell et al., 2003), were followed when feasible, given the exposure data. See details for each factor in below chapters and overview in Table 1.

The data on the background level of different diseases and age group structure was estimated for this area from the Global Burden of Disease Study 2010 (2013) country files. GBD 2010 country files have information at the national level on background DALYs, YLLs, YLDs and deaths divided between different causes, gender and age groups. The background burden estimates are undiscounted and unweighted for age, following the Global Burden of Disease Study 2010 (2013) approach (Murray et al., 2012). The background burden for Warsaw was estimated from national data by taking account population size, gender and age structure differences between Poland and Warsaw. The population data was obtained from the Central Statistical Office (2012), Poland. The background burden data used in this study is presented in Table 2.

### 2.3. Air pollution

The exposure to air pollution generated by local transport was estimated for eight air pollutants: $PM_{2.5}$ (fine particulate matter, particulate matter with aerodynamic diameter less than 2.5 μm), $PM_{2.5-10}$ (coarse particulate matter, particulate matter with aerodynamic diameter in between 2.5 and 10 μm), nitrogen oxides ($NO_x$), sulfur dioxide ($SO_2$), benzo [a] pyrene (BaP), nickel (Ni), cadmium (Cd), and lead (Pb). These pollutants were chosen because of their potential to generate adverse health effects (Hanninen et al., 2014; Lim et al., 2012; United States Environmental Protection Agency, n.d.).

The exposure was estimated with the Gaussian puff dispersion model CALPUFF, version 5 (http://www.src.com/calpuff/calpuff1.htm). Details of the dispersion modeling and exposure assessment has been described in Holnicki and Nahorski (2013) and Tainio et al. (2014), respectively. In short, the dispersion modeling was done with $1 \times 1$ $km^2$ spatial resolution over the study area. The emission data for different air pollutants was obtained from EKOMETRIA, Poland (http://www.ekometria.com.pl/) and it included both tailpipe emissions of pollutants as well as PM raised by road traffic. The population data was obtained from the European Environment Agency (2008). The exposure was calculated as the population-weighted mean concentration of pollutants in the air. The annual average exposure for these pollutants is presented in Table S3 (Supplementary material).

For the health calculations the PM air pollution was divided to two fractions, $PM_{2.5}$ and $PM_{2.5-10}$, because these fractions cause different health effects (see details below). $PM_{2.5}$ fraction includes primary $PM_{2.5}$ emitted from car exhausts, secondary PM formed from the gaseous $SO_2$ and $NO_x$ emissions, and the fine dust raised from the road due to transport. $PM_{2.5-10}$ contains primary PM emitted from car exhausts and fine dust raised by the traffic. For other air pollutants only exhaust emissions were taken into account.

#### 2.3.1. Health calculations for air pollution

The exposure-response functions (ERFs) for different air pollutants and health outcomes are summarized in Table 1 and the background burden data in Table 2. We provide an overview of the methods and data sources below. Further details are provided in the Supplementary material (Chapter 2).

For the PM air pollution we estimated increased natural-cause mortality due to $PM_{2.5}$, new cases of chronic bronchitis due to $PM_{2.5}$ and $PM_{2.5-10}$, restricted activity days (RADs) due to $PM_{2.5}$, and lower respiratory symptom (LRS) days for the school children and for the adults due to $PM_{2.5}$ and $PM_{2.5-10}$. The same health outcomes were modeled in the EBoDE study (Hanninen et al., 2014).