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MODELLING THE AIR QUALITY FOR ASSESSING THE URBAN PUBLIC HEALTH IMPACT: A CASE OF URBAN REGENERATION IN TALLINN, ESTONIA

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Abstract: The long-term average concentrations of nitrogen dioxide and fine particulate matter were modelled for central part of Tallinn city, the capital of Estonia, to assess the health impact of a future urban regeneration scenario, where in two main streets number of traffic lines will be reduced. This will decrease traffic amounts and creates more friendly space for pedestrians and bicyclers. In the analysis current situation is evaluated and two sub-scenarios with different restrictions are considered. The stationary Gaussian plume model AEROPOL was used for calculations in 4.5 km^2 model domain with 25 m grid resolution. The meteorological data set consists of hourly ground-based observed values from years 2010-2014. The HBEFA emission factors (TU Graz) were applied to estimate the traffic emissions from modelled traffic flows. The national air quality monitoring data was used to fit the background concentrations and derive the empirical fraction of NO_2 in total NOx emitted to the air. The health impacts were calculated based on air pollution exposures on residents, and daily visitors in the area of 1.3x1.45 km, current base-line mortality values and exposure-response functions. Validation against the measured concentrations in an air quality monitoring station within the grid shows moderate overestimation in the exact location, but the spatial precision of modelling is not sufficient to locate exactly the high concentrations at certain street side. In the future scenarios, along with reduced concentrations in the citycentre, the concentrations increase slightly near the main traffic streets in periphery, where the transit traffic is redirected. In total reduction of exhaust (indicated by NO_2) and road dust (indicated by PM_{10}) exposures in the city centre would save every year 0.29 premature deaths among general population, 0.57 deaths among daily visitors, 0.18 deaths among pedestrians and 0.03 deaths among people in public transport.

Key words: *nitrogen dioxide, fine particulate matter, Gaussian dispersion model, urban air pollution, public health, mortality, premature death.*

INTRODUCTION

Urban air pollution is a serious public health risk. For instance it has been found that in the central part of Tallinn, the capital city of Estonia (about 400 thousand inhabitants), the air pollution reduces the life expectancy more than by a year (Orru et al., 2009). The most problematic pollutants in the air of European cities are particulate matter (PM_{10}) and nitrogen dioxide (NO_2), increasing the risk of cardiovascular and respiratory system diseases and thus, causing excess premature deaths. In Nordic countries due to high emissions of street dust, the majority of the PM_{10} mass is $PM_{2.5-10}$ (Johansson et al., 2007).

This paper is aimed to estimate the change in the traffic exhaust (indicated by nitrogen dioxide) and road dust (indicated by PM_{10}) and to assess the reduction of health impact in central part of Tallinn City for a future urban regeneration scenario. According to the scenario, in two main streets number of traffic lines will be reduced. This will decrease traffic amounts and create more friendly space for pedestrians and bicyclers. In this analysis the current situation is evaluated and two sub-scenarios with different restrictions are considered.

MODELS AND METHODS

Site and scenario

The Tallinn City lays more than 20 km along the coastline of Gulf of Finland, the northern coast of Estonia, being only 3 – 7 km wide across the coastline. In its central part two main traffic streets approach the central square, in immediate neighbouhood of old town, from south-west and east, thus constituting an about 2 kilometres long transit traffic route, here called the main street, between the western and the eastern parts of the town through the citycentre. The current situation is further referred as V0. The urban regeneration project includes two sub-scenarios:

- V1 – only public transport and one traffic line for motorized vehicles through the main street;
- V2 – only public transport passes through the central square, however, the access for private cars to its neighbourhood is granted from both sides.

Here the new traffic scheme is assumed due in close future, thus the effect of expected cleaner engines in future is not considered, all the the changes in air pollution patterns and public health indicators are the effects of changed traffic loads only.

Air pollution modelling

The AEROPOL model (Kaasik & Kimmel, 2004), version 5.3 is applied for dispersion modelling. Currently the urban air canopy porosity concept (Genikhovich et al, 2002), earlier succesfully used to correct the Gaussian dispersion within the canopy (Kaasik et al., 2014), is incorporated into the model code. The emission data from streets are based on traffic counting (current situation, V0) and modelling with CUBE software provided by Stratum AS (future scenarios, V1 and V2). The HBEFA emission factors (TU Graz, 2009) are applied to estimate the traffic emissions from measured or modelled traffic flows, considering the vehicle fleet data from the national register. The emissions from road pavement were taken into account, which according to (Omstedt et al., 2005) constitute a major part of particulate matter emissions in North European cities due to use of studded tyres. In this study a simplified form of NOTRIP emission method (Norman et al., 2016) is used, assuming 25% of studded tyres as annual average.

The air pollution modelling was carried out in 4.5 km^2 model domain with 25 m grid resolution. The meteorological data set consists of hourly ground-based observed values from years 2010-2014. Transition from emitted NOx to NO_2 is based on a regression formula derived from urban air quality monitoring in Estonia. Also, the background values were assigned according to urban monitoring data.

Health impact modelling

The health impacts were calculated, based on population-average exposures to $PM_{2.5\text{-}10}$ and NO_2 among residents and daily visitors in the area of 1.3x1.45 km, as well as pedestrians and people in public transport. The number of current residents and daily visitors was based on population census data in 100x100 m grids in 2011. The future populations were calculated, based on population prognosis from 2030 in central part of Tallinn (Tammaru, 2011). The number of pedestrians in one time moment was counted using Google Street View all-over Tallinn main street area. The annual average number of pedestrians was calculated, based on trends discovered in pedestrians countings in six main crossing from 7 am to 11 pm in four different seasons. The number of people in public transport and time spent in the transport modes was retrieved from Tallinn Transport Department’s statistics. The number of premature deaths was calculated with the following equation:

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

where Y_0 is the baseline mortality rate; *pop* the number of exposed persons; β is the exposure-response function (calculated based on relative risk (RR)) and X the estimated excess exposure.

The baseline mortality rate was retrieved from Statistics Estonia and relative risks from earlier epidemiological studies: for NO_2 meta-coefficient as RR = 1.055 (95% CI=1.031–1.080) per increase of annual average concentration by 10 µg/m^3 among 30+ years old residents (WHO, 2013) and for $PM_{2.5\text{-}10}$

as RR = 1.018 (95% CI=1.0115–1.0245) per increase of annual average concentration by 10 µg/m^3 among all residents (Meister et al., 2012), in both cases for increase of non-external mortality.

RESULTS AND DISCUSSION

Air pollution levels

Modelled current annual average concentrations (V0) of PM_{10} and NO_2 are presented in Figure 1. Validation based on measured concentrations in the single street air quality monitoring station within the grid, show moderate overestimation in the exact location, but the spatial precision of modelling is not sufficient to locate exactly the high concentrations at certain street side. The current concentration map includes a few hot-spots near main traffic junctions within densely built-up areas.

Comparision of air pollution levels in two alternatives V1 and V2 with current situation V0 for PM_{10} and NO_2 are presented in Figures 2 and 3 respectively. Both alternatives provide a considerable reduction of pollution near the main street and at the central square in particular, where the modelled NO_2 levels are currently exceeding the limit value 40 µg/m^3. The concentrations near the streets in periphery will increase slightly due to increased transit traffic. The spot of highly increased concentrations near the passenger port at northeaastern corner of the domain is due to a new traffic street included to the scenario.

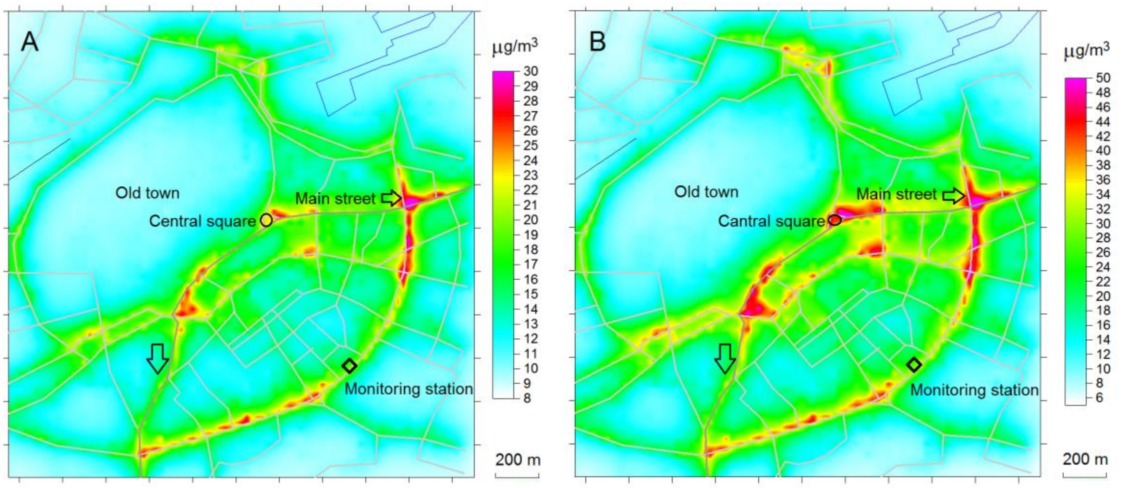

Figure 1. Modelled current annual average concentrations of PM_{10} (A) and NO_2 (B).

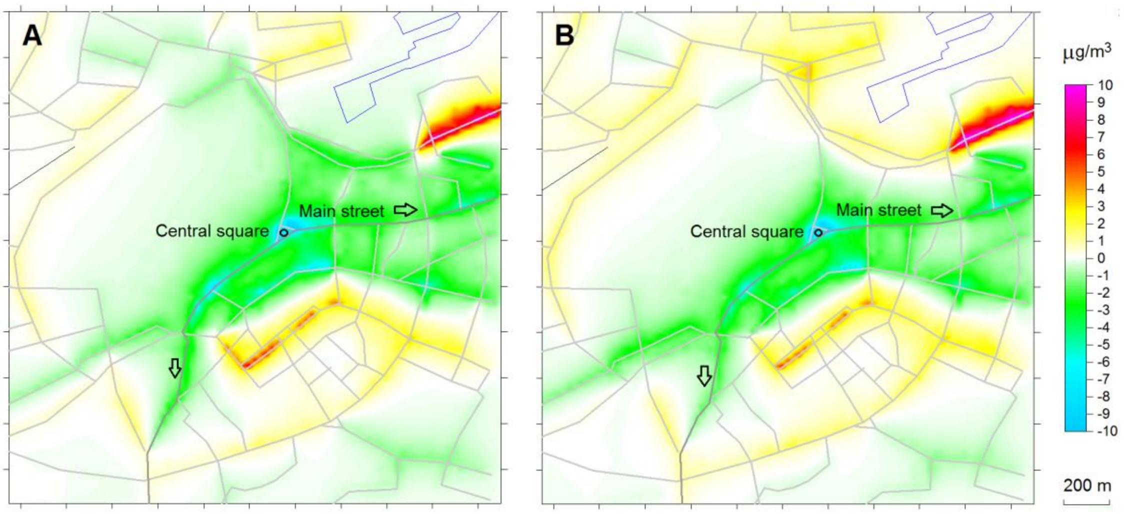

Figure 2. Changes in annual average concentration of PM_{10} in case of sub-scenario V1 (A) and V2 (B) in respect to current situation V0.

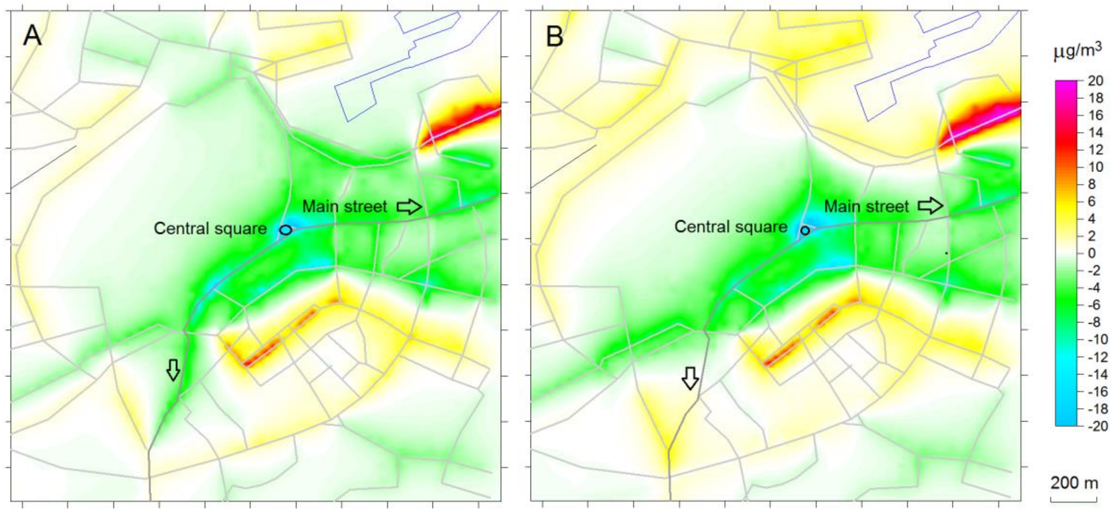

Figure 3. Changes in annual average concentration of NO_2 in case of sub-scenario V1 (A) and V2 (B) in respect to current situation V0.

Table 1. Emissions from the main street and entire citycentre at rush hour (gs^{-1}). The rush hour traffic flow is assumed 2.4 times larger than daily average.

	V0 (current situation)		V1 (public transport and one lane)		V2 (public transport only)	
	Main street	Centre	Main street	Centre	Main street	Centre
PM_{10}	0.43	3.89	0.35	3.75	0.29	3.89
NO_2	0.87	6.66	0.70	6.51	0.67	6.74

Only slight reduction of pollution levels in the central area is expected, comparing the stricter scenario V2 with the V1, the milder one. The emissions from the main street will be reduced considerably in scenario V1 and even slightly more in V2 (Table 1), but the total emissions from the citycentre will increase in V2 due to longer transit traffic routes in periphery.

Health impacts

In total, reduction of NO_2 and PM_{10} exposures in the city centre would save each year 0.26, and 0.03 premature deaths among general population, 0.52, and 0.05 deaths among daily visitors, 0.13, and 0.05 deaths among pedestrians and 0.02, and 0.01 deaths among people in public transport, respectively (Table 2).

Table 2. Number of premature deaths (95% CI) annually due to exposure to NO_2 and PM_{10} among residents, daily visitors, pedestrians and people in public transport.

	Due to NO_2 exposure	Due to PM_{10} exposure
Residents		
V0 (current situation)	9.48 (5.56–13.26)	1.19 (0.14–2.15)
V1 (public transport and one traffic lane)	9.28 (5.43–12.98)	1.15 (0.14–2.07)
V2 (public transport only)	9.22 (5.40–12.90)	1.16 (0.14–2.10)
Daily visitors		
V0 (current situation)	14.02 (8.21–19.62)	1.66 (0.20–3.00)
V1 (public transport and one traffic lane)	13.59 (7.95–19.00)	1.59 (0.19–2.87)
V2 (public transport only)	13.50 (7.91–18.88)	1.61 (0.19–2.92)
Pedestrians		
V0 (current situation)	0.64 (0.37–0.90)	0.21 (0.04–0.38)
V1 (public transport and one traffic lane)	0.53 (0.31–0.74)	0.17 (0.03–0.31)
V2 (public transport only)	0.51(0.29–0.72)	0.16 (0.03–0.30)

Table 2.

	Due to NO_2 exposure	Due to PM_{10} exposure
People in public transports		
V0 (current situation)	0.09 (0.05–0.13)	0.03 (0.01–0.05)
V1 (public transport and one traffic lane)	0.07 (0.04–0.11)	0.02 (0.01–0.04)
V2 (public transport only)	0.07 (0.04–0.11)	0.02 (0.01–0.04)

CONCLUSIONS

The planned urban regeneration, limiting the transit traffic across the citycentre of Tallinn, affects considerably and positively the air pollution levels and public health condition in the citycentre.. However, the effect of strict limitation of private transport has contraversy effects compared to the milder version of reamaining one traffic lane: along with slight reduction of pollution in the very centre, the general emissions increase due to redirected transit traffic in periphery. Thus, the one-lane version V1 seems to be preferable.

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REFERENCES

Genikhovich, E., Gracheva, I., Filatova, E, 2002: Modelling of urban air pollution: principles and problems. In: Borrego C, Schayes G (Eds.) Air pollution modelling and its application, XV, Kluwer, 275–283.

Johansson, C., Norman, M., Gidhagen, L., 2007: Spatial and temporal variations of PM_{10} and particle number concentrations in urban air. Environ. Monit. Assess., **127**, 477–487.

Kaasik M, Pindus M, Tamm T, Orru H., 2014: The porosoty concept applied to urban canopy improves the results of Gaussian Dispersion modelling of traffic-dominated emissions. In: Steyn, D., Mathur, R. (Eds.) Air Pollution Modelling and its Application, XXII, Springer, 417–420.

Kaasik, M., Kimmel, V., 2004: Validation of the improved AEROPOL model against the Copenhagen data set. Int. J. Environ. Pollut., **20** (1–6), 114–120.

Meister, K., Johansson, C., Forsberg, B., 2012: Estimated short-term effects of coarse particles on daily mortality in Stockholm, Sweden. Environ. Health Persp. **120** (3), 431–436.

Norman, M., Sundvor, I,. Denby, B.R., Johansson, C., Gustafsson, M., Blomqvist, G., Janhäll S., 2016: Modelling road dust emissioon abatement using the NOTRIP model: Vehicle speed and studded tyre reduction. *Atmospheric Environment*, **134**, 96–108.

Omstedt, G., Bringfeldt, B., Johansson, C. 2005: A model for vehicle-induced non-tailpipe emissions of particles along Swedish roads. *Atmospheric Environment*, **39**, 6088–6097.

Orru, H., Teinemaa, E., Lai, T., Tamm, T., Kaasik, M., Kimmel, V., Kangur, K., Merisalu, E., Forsberg, B., 2009: Health impact assessment of particulate pollution in Tallinn using fine spatial resolution and modelling techniques. *Environmental Health*, **8**, DOI: 7.10.1186/1476-069X-8-7.

Tammaru, T. 2011. Tallinna rahvastikuprognoos 2011–2030. Konsultatsiooni- ja koolituskeskus Geomedia, Tartu, 59 pp.

TU Graz., 2009: Emission Factors from the Model PHEM for the HBEFA Version 3. Report Nr. I-20/2009 Haus-Em 33/08/679 from 07.12.2009. Graz University of Technology, Institute for Internal Combustion Engines and Thermodynamics, 76 pp.

WHO, 2013. Health risks of air pollution in Europe – HRAPIE project. Recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide. WHO Regional Office for Europe, Copenhagen, 54 pp.