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IMPROVING LARGE-SCALE NO_2 EXPOSURE ASSESSMENT BY INTEGRATING AIR QUALITY DATA FOR STREET CANYONS

Florian Pfäfflin, Volker Diegmann, Lina Neunhäuserer

IVU Umwelt GmbH, Emmy-Noether-Straße 2, 79110 Freiburg, Germany

Abstract: Assessment of health effects due to air pollution is often based on exposure assessments that use spatially differentiated modelled background concentrations. Especially for NO_2 with its strong gradient with increasing distance from the source and high concentrations in built-up street canyons, this approach underestimates exposure. To better asses the exposure also for high NO_2 concentrations, the coarse results of the model representing the background concentrations were exemplarily extended by refined background concentrations and data on small-scale traffic-related NO_2 exposure for selected sample regions. This was achieved with the method of segment-based exposure (SBE) that attributes parts of the population of each background grid-cell to respective street segments and their higher concentrations, ensuring that no double counting of exposed persons takes place.

Key words: NO_2, exposure, environmental burden of disease, model, background, street canyon, screening, SBE.

INTRODUCTION

Assessment of health effects due to air pollution is often based on exposure assessments that use spatially differentiated modelled background concentrations, as in the recent study on behalf of the German Environment Agency (UBA) "Quantification of the burden of disease attributable to nitrogen dioxide exposure in Germany" (UBA, 2018). The study has been carried out in cooperation of the Helmholtz Zentrum München and IVU Umwelt to provide a nationwide estimation of the background NO_2 exposure of the population in Germany with a subsequent quantification of the related environmental burden of disease for mortality and morbidity. In that study, nationwide data sets of NO_2 exposure to background concentrations for the years 2007 to 2014 were analysed based on modelled NO_2 data of the German Environment Agency and measured NO_2 data of the federal government and the federal states.

Generally, with increasing domains the model resolution gets coarser and is in the range of 1 km to several km ground resolution when entire countries are being assessed. Especially for NO_2 with its strong gradient with increasing distance from the source and high concentrations in built-up street canyons, this approach underestimates exposure. To better asses the exposure of the population also for high NO_2 concentrations, an approach has been developed to extend the coarse results of the modelled background concentrations to include refined background concentrations and especially data on elevated concentrations in street canyons by using additional model results from small-scale screening studies for built-up street segments. The new dataset created with this approach was used in an exposure assessment for three sample areas and results were compared to the standard assessment based on coarse modelled background concentrations only.

The paper presented here does not intend to present all aspects of the aforementioned study but rather focuses on the methodology developed to include local elevated concentrations due to road traffic in street canyons in exposure assessment.

BASE ESTIMATION OF NO_2 EXPOSURE IN GERMANY

In order to assign a specific NO_2 exposure to the entire German population as basis for an estimation of the burden of disease for Germany, both measured and modelled data on NO_2 concentrations in ambient air were used. Basis of this nationwide estimation were data on the spatial distribution of NO_2 annual averages from data modelled with the three dimensional chemical transport model REM/CALGRID (RCG, Stern, 2010) for the years 2007 to 2014 with a spatial distribution of about 7 km x 8 km combined with measurement data by means of optimal interpolation, and data on the spatial distribution of the number of inhabitants for the reference years 2005 and 2011 with a spatial resolution of 0.25 km x 0.25 km.

To estimate the NO_2 exposure data, grid cells with a spatial extent of 1 km x 1 km were defined as smallest geographic units in which the population was linked to specific concentrations. Both inhabitants and concentration levels were redistributed to this raster without any interpolation. Based on the grid-related NO_2 concentrations and population numbers, respective population distributions were derived. The calculated averaged population weighted NO_2 concentrations for the concentration classes provided the basis for the calculation of the environmental burden of disease of various NO_2 specific health outcomes.

In addition, population weighted NO_2 exposure indicators were determined from the grid data as weighted sums, following a method previously used by the UBA (Kallweit and Wintermeyer, 2013). These are shown together with the development of the annual mean NO_2 concentrations in Germany in Figure 1. The population weighted NO_2 exposure indicator is higher than the NO_2 concentrations, because higher NO_2 concentrations occur mainly where many people live. The population weighted NO_2 exposure indicator is decreasing from 2007 to 2014 with approximately the same magnitude as the NO_2 concentrations.

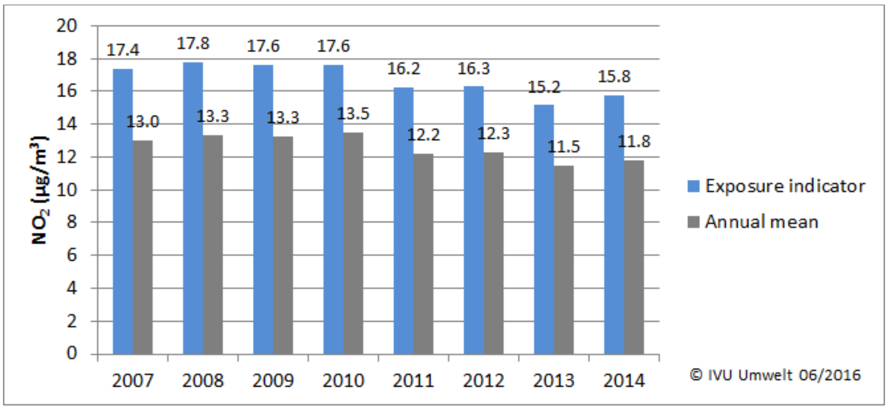

Figure 1: NO_2 exposure indicator weighted by residents and annual average NO_2 concentrations representative for the rural and urban background areas in Germany for the years 2007 to 2014.

INCLUSION OF SMALL-SCALE CONCENTRATIONS

In order to be able to give as complete evidence as possible for the exposure of the population even for high NO_2 concentrations, the coarse data representing the background concentrations described above were replaced by refined background concentrations and extended to include data on smaller scale traffic-related NO_2 exposure.

Sample regions and data

A complete evaluation of the small scale NO_2 exposure of the entire federal state of Germany was not feasible due to a lack of necessary input data and the computational effort. Therefore, the assessment of the small scale NO_2 exposure was conducted exemplarily for selected sample regions. The sample regions chosen were the urban area of Berlin (Senat Berlin, 2013; IVU Umwelt, 2014), the federal state of Brandenburg (IVU Umwelt, 2015) and the urban area of Munich (IVU Umwelt, 2013) as the necessary model and measurement data were available there and these regions have different characteristics due to their respective structure regarding geographical locations, NO_2 concentration levels and population densities. All data used was compiled during standard air quality assessment and planning activities.

For the sample regions, data on background concentration were available on a spatial grid of 1 km x 1 km resolution and used to replace the coarse nationwide background data. Data on local concentrations in built-up streets was available from screening calculations with the model IMMIS^{luft} (IVU Umwelt, 2016a). Screening models use simplified methods and few input data to calculate concentrations in built-up road segments with a homogeneous building structure and a homogeneous emission situation along the segment. Data of all sample regions were consolidated to a common reference year 2013, following the approach described in IVU Umwelt (2016b).

Results of a model-based concentration distribution for the annual mean NO_2 value originating in the air quality planning for Berlin are shown in Figure 2. The classification is the same for both the urban background concentrations and the road segments. Calculated NO_2 concentrations are high in the inner-city area and decrease towards the edges of the city. The urban background concentration, represented as raster cells, reaches a maximum of 24 µg m^{-3}. The peak concentration for the screening sections is 69 µg m^{-3}. As Figure 2 shows, the spatial density of the screening sections is very high, especially in inner-city areas.

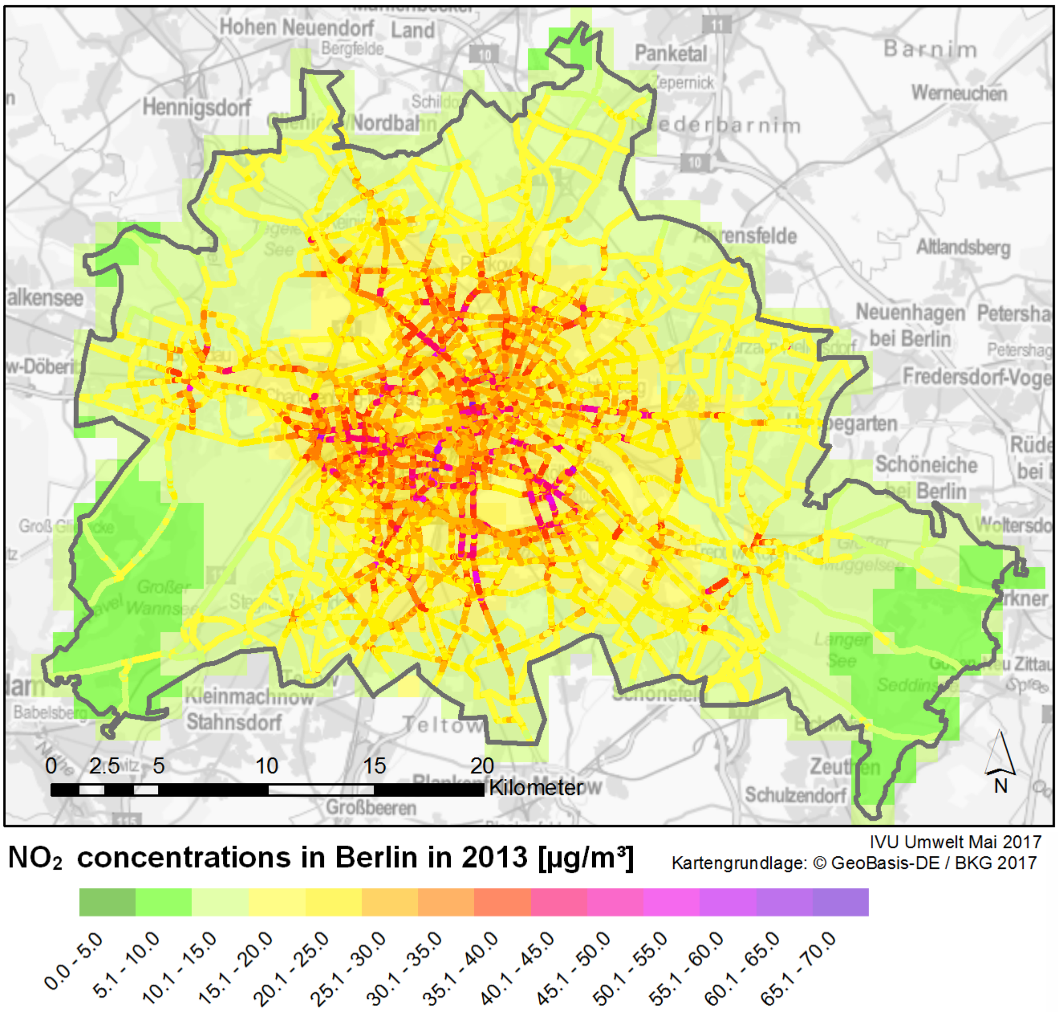

Figure 2: NO_2 concentrations in Berlin in 2013 for background grid cells and built-up street segments

Segment-based exposure (SBE)

To complement the background concentration with these screening data for built-up roads the so-called segment-based exposure (SBE), first introduced in IVU Umwelt (2016b), was used. With the SBE method, population densities in a regular grid can be assigned partly to segment-related pollutant concentrations from screening studies and partly to background concentration. Since each grid cell can contain segments of several screening sections with different concentration values, population values have to be assigned to these segments separately. To do so, the approach outlined in Figure 3 is used.

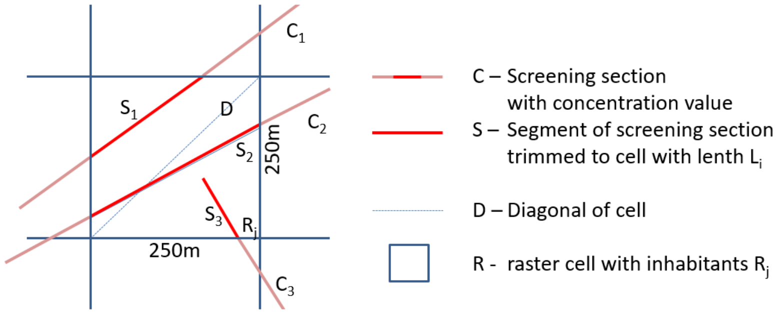

Figure 3: Scheme of the allocation of the grid-based population data on a 250 x 250 m² raster to the screening sections and segment-based concentrations

The sections of the screening calculations with concentration values (C_i) are split to segments (S_i) using the raster of the population data such that each segment is completely within one raster cell (R_j). Then, for each segment S_i its length L_i is determined. Depending on the sum of the length of all segments (ΣL_i) in raster cell Rj, the proportion of the total population of this raster cell (POP_{Rj}) that is assigned to the segments in the cell is determined. Above a defined threshold value (*TL)* for ΣL_i all inhabitants are regarded as affected by local traffic related concentrations and are completely distributed to the segments within that cell. The fraction of inhabitants of grid cell R_j affected by local traffic-related concentrations is sub-distributed to the individual segments S_i according to their respective share of ΣL_i. The threshold value *TL* was derived in IVU Umwelt (2016) based on detailed data on people affected by values above the annual limit value for PM10 concentrations and set to three times the length of the diagonal of the grid cells.

The population (POP_{Si}) allocated to the segment S_i, respectively its concentration value, is thus calculated according to the following formula:

$$POP_{S_i} = {}^{L_i}/_{\sum_i L_i} * \begin{cases} POP_{R_j} & if \displaystyle\sum_i L_i > TL \\ {}^{\sum_i L_i}/_{LS} * POP_{R_j} & if \displaystyle\sum_i L_i \leq TL \end{cases}$$

The inhabitants in a grid cell that are not assigned to a segment are linked to the background concentration. By this approach, each inhabitant gets uniquely assigned to a concentration value, either taken from one of the screening sections that cross his respective grid cell or taken from the background concentration of that grid cell. The fraction of inhabitants assigned to concentrations of street segments in the three sample regions are quite similar, ranging from 9.3 % in Brandenburg to 11.4 % in Berlin with an average of 10.4 %.

Increased exposure and environmental burden of disease

Using this refined data, the population weighted NO_2 exposure indicator and the burden of disease were estimated for the sample regions using the same methodology as for the nationwide assessment. The population weighted NO_2 exposure indicators are significantly increased by this higher level of detail. The absolute indicator increases by 2 µg m^{-3} in Berlin and by 3 µg m^{-3} in Brandenburg. In Munich, the increase is most pronounced with over 6 µg m^{-3}. Looking at the relative changes of the indicator, in Berlin only a slight increase of 5 % is due to the refinement of the background concentrations. Additionally considering the SBE-based screening results leads to a significant increase of the indicator by 12 % compared to the base case. With a value of 30 % the total increases of the indicator due to the refinement are more pronounced in Brandenburg and Munich. There, however, the major part of the increase is due to the refinement of the background concentration which in these regions differs more from the coarse data than in Berlin. Averaged across all three sample regions, the indicator increases by 2.3 $\mu g\ m^{-3}$ respectively 16 % due to the refined background and by 3.1 $\mu g\ m^{-3}$ respectively 21 % when including the SBE-based screening results. Regarding the environmental burden of disease, years of life lost respectively premature deaths increase by over 160 % for the sample region with a low population density. Sample regions representing agglomerations with a high population density show increases between 40 to 52 %.

SUMMARY

The segment-based exposure (SBE) is a straightforward and easy-to-use approach to combine model results from different scales in an overall large-scale exposure assessment. It complements background concentrations with detailed air quality data from screening models that are routinely used for cities and regions in standard air quality assessment and planning activities. Increasing the resolution of background concentration data and additionally considering locally elevated NO_2 concentrations in built-up roads significantly increases both the population-weighted NO_2 exposure indicator and the environmental burden of disease.

Due to the rather large range of changes in the impact indicators when using the refined data compared to the nationwide assessment, a uniform transfer of the results to other areas cannot be done easily. The variations that occur are not very large in absolute terms, but show clear differences in a relative comparison. These are caused by the different structural characteristics of the individual regions. The differing data bases in the sample regions can also have an influence on the extent of the change. However, due to the very similar general modelling approach and the equal screening method in all regions, the authors consider the structural differences between the regions to be significant. An in-depth analysis of the variability of the refinement methods on the exposure estimate was beyond the scope of the project. This could be done either by refining the model regions with identical data bases and methodologies or by analysing more sample regions.

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