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Representativeness of air quality monitoring networks

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HIGHLIGHTS

- Air quality networks in cities show important difference in design.
- Differences in design of air quality networks may lead to exposure assessments that are hard to compare.
- Differences in design of air quality networks may lead to unbalanced checking of compliance.
- Models are needed to support data evaluation network evaluation.

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ABSTRACT

The suitability of European networks to check compliance with air quality standards and to assess exposure of the population was investigated. An air quality model (URBIS) was applied to estimate and compare the spatial distribution of the concentration of nitrogen dioxide (NO_2) in ambient air in four large cities. The concentrations calculated at the location of the monitoring stations, compared well with the concentrations measured at the stations indicating that the models worked well. Therefore the calculated concentration distributions were used as a *proxy* for the actual concentration distributions across the cities. The distributions of these proxy concentrations across the city populations was determined and cumulative population distribution curves were estimated. The *calculated* annual mean values at the monitoring network stations were located on the population distribution curves to estimate the fractions of the populations that the monitoring network stations represent. This macro scale procedure is used to evaluate which subgroups of the monitoring stations can be reliably used to decide on compliance or to estimate the concentration the population is exposed to. In addition, the CAR model and Computational Fluid Dynamics (CFD) models are used to investigate the effect of micro scale siting of the monitoring stations within the streets.

The following observations were made:

- Berlin and London networks cover the distribution of concentrations to which the population is exposed rather well, while Stuttgart and Barcelona have stations at sites with mainly the higher concentrations and the exposure is covered less well.
- The networks in London and Berlin, with a substantial number of urban background stations, seem fit to monitor the average population exposure, contrary to those in Stuttgart and Barcelona with only a limited number of these stations.
- The concentrations measured at street stations hardly reflect the calculated differences in street pollution between the cities. In Stuttgart the stations are, in line with the EU directive, placed in the most polluted streets, while in other cities there are no stations in the streets with the highest pollution levels.
- The concentrations measured at street stations – particularly where buildings inhibit ventilation – are very sensitive to the exact location within the street. Different siting choices may have an effect that for NO_2 could reach up to 10 $\mu g/m^3$ in realistic conditions. Street stations, representing only a small urban area, are not suitable for characterising the exposure of the general population.

It is important to note that epidemiological studies whether investigating short term-effects or those studying long-term effects are potentially affected by the issues raised in the paper. Long-term cumulative exposure estimates that are based rather uncritically on monitoring data may be biased if the stations are not representative. It is recommended to use models to support the interpretation and spatial extrapolation of the results of measurements in existing networks. The use of models also relaxes the need for station relocation in inadequate networks, which often would compromise trend analysis. It

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also relaxes the importance of exact or detailed, comprehensive, station classifications since all stations can be used in exposure assessments.

1. Introduction

1.1. Background

In the course of time EU legislation was developed to monitor air quality throughout the member states. Data quality objectives in this legislation have set requirements for the quality of the measurements and the data coverage in time. These provisions together with legal requirements on station density and siting, have helped to limit the substantial differences that originally existed between the networks in the member states.

By now, a generally accepted practice of standardising monitoring equipment including protocols for quality assurance and quality control have become available. There are however still important differences in the spatial coverage of the various networks. In a recent survey of views of member states and other stakeholders on the revision of the EU Ambient Air Quality Directive (AAQD[1]), further harmonisation of the networks, in particular regarding station siting (and representativeness), was high on the priority list (van den Hout et al., 2012).

The foremost purpose of the monitoring networks operating in the states is to assess compliance with the air quality standards of the EU AAQD. The second important purpose is to assess exposure of people, addressing both the highest levels and the levels in other areas where the general population is exposed. In this study we focus on these two objectives, i.e. *determination of compliance* and *exposure assessment* and the adequacy of current networks regarding these two objectives.

In view of these discussions representativeness could indicate *spatial* representativeness (how large is the area represented by the measurements at a certain station). This is a very difficult issue. On the other hand it could also indicate how well measurements at a certain station represent the *exposure* of the general population. Partly this indication overlaps with the previous one. But it is perhaps easier to address and the focus of this study.

1.2. Exposure and network design

The actual exposure of a person is determined by the concentration in the breathing zone. It should be noted that the total exposure of (European) individuals to air pollutants is more related to indoor air than ambient air monitored at stations. This is illustrated in Fig. 1 showing an example of how people spend their time (Dons et al., 2011).

Exposure as mentioned in the AAQD however relates exclusively to ambient outdoor air.[2] In Annex III of the AAQD on siting requirements, exposure it is not further specified; only in the definition of the Average Exposure Indicator some specification is given,

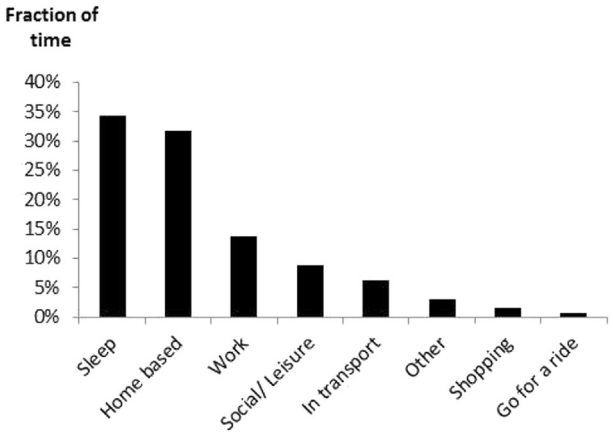

Fig. 1. An example of the fraction of time that people in Belgium spend on certain activities. Derived from Dons et al. (2011).

relating the average exposure to urban background sites (Article 2#). Although both outdoor and indoor air (including outdoor air penetrated indoors) are important contributors to the actual exposure, the concentration-response functions established in epidemiological studies, on which the air quality standards are based, relate only to outdoor concentrations – usually those measured at urban background locations (Hoek et al., 2002; Boezen et al., 1999).

In the study here we assume exposure is directly linked to the home address. This is the place where people spend most of their time as illustrated in Fig. 1.

Exposure as described in the AAQD Annex IIIB is derived from measurements at stations, which are always limited in number. Obviously most people do not actually live in the direct vicinity of monitoring stations. In (urban) background conditions concentration gradients are usually small, so measurements at these stations tend to be quite representative for larger areas and are consequently suitable to assess exposure.

As outlined above, the foremost aims in air quality monitoring are to assess compliance with air quality standards and population exposure, including trends therein. A network should address both issues. We will study the networks of four large European cities bearing these goals in mind. Two scales are distinguished here:

Macro scale siting of a station is the selection of the type of site (urban background, near streets etc.) and the approximate location. In Annex III to the AAQD provisions on macro siting are given: "Sampling points directed at the protection of human health shall be sited in such a way as to provide data on the following:"

- the areas within zones and agglomerations where the highest concentrations occur to which the population is likely to be directly or indirectly exposed for a period which is significant in relation to the averaging period of the limit value(s),
- levels in other areas within the zones and agglomerations which are representative of the exposure of the general population"[3]

[1] The Lancet, Volume 353, Issue 9156, Pages 874–878, 13 March 1999.

[2] It is relevant to note here that time activity patterns shown in Fig. 1 may lead to different assessments. In the study by Dons et al., 2011 it is shown that drivers may be exposed to rather significant levels of black carbon (a component emitted by cars) during the period they drive to their work. Exposure at home is much less due to the much lower levels there. This issue, although interesting, is not addressed here at this stage and we follow the directive's approach where exposure relates to ambient outdoor air quality.

[3] Article 2 of the AAQD: 'urban background locations' shall mean places in urban areas where levels are representative of the exposure of the general urban population.