Small-scale differences of urban NO$_x$ exposition in field measurement data

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Abstract

Local differences in air pollution levels of different positions of even close points along a street can be dramatic due to mainly meteorological parameters and local geometry. Air pollution monitoring systems provide a huge amount of temporal data, but the number of monitoring sites is far from sufficient for fine spatial investigations. On the other hand, for reliable air pollution modelling and correct prediction of expositions, a more detailed spatial distribution of samples is needed. Small-scale differences and street canyons are often investigated by models. However, such small-scale real field data from direct measurements are rarely available. In this paper we provide evidence by measurements to the existence of significant small-scale differences in air pollution levels and provide data for model validation. Hence, we performed measurements inside a single crossing and along three main roads in the city of Győr. Air samples were sucked into Tedlar bags and NO$_x$ concentration was determined by a gas analyser using a chemiluminescent method. On the sampling days manual traffic counting and noise measurements were performed and meteorological data were also taken at the same time. Daily rhythm and spatiotemporal variation of NO$_x$ expositions were investigated and compared to traffic data and data from the two monitoring containers of Győr. We observed a similar daily profile as expected in an average workday out of heating season: a sharp peak in the morning and a wider rise of nitrogen oxide concentration in the afternoon. Canyon effects were detected inside the investigated crossing. It caused a difference in pollutant levels of the two sides of the street. Despite a relatively small number of sampling sites, significant differences were detected both inside the crossing level and between main streets at $p = 0.055$.

Keywords: NO$_x$, street canyon, field measurement, traffic pollution, Hungary.
1 Introduction

Ambient air pollution is associated with significant adverse effects on public health. Regarding the most critical pollutants (O$_3$, PM$_{2.5}$, PM$_{10}$ and benzo(a)pyrene) one quarter of the urban population of the EU is exposed to concentrations exceeding EU reference levels [1]. Most of the urban population (97–98%) is exposed to higher levels of ozone, as assigned in WHO’s air quality guidelines [2, 3].

Nitrogen oxides are also monitored as primary ozone precursors. The road transport sector is the most important contributor to European NO$_x$ emissions and estimated to represent more than 40% of total nitrogen oxides emissions [3]. The proportion of transportation in Hungary exceeds 50% according to the data of the Hungarian Central Statistical Office [5]. Since demand for transportation continues to exceed improvements to emission reduction technologies, intra-urban traffic pollution is not decreasing as required [6].

For more than a decade monitoring data have been available about main pollutants of the major cities all around Europe. They provide sufficient temporal data for describing trends and differences between towns or main parts of larger cities. However, a single central monitoring site or two per city are far from the required spatial distribution for studying small-scale differences, which would also be necessary to better estimate personal exposures [7]. Recent studies have shown that, for some pollutants associated with traffic, such as nitrogen dioxide and ultrafine particles, variation within cities may exceed variations between cities [8], [6].

Small-scale differences and canyon effects have become of higher importance [10, 11]. Most studies based on modelling [7, 8] calibrated with monitoring data. Spatially detailed field measurements are rarely available. Targeted monitoring campaigns for model calibration and validation gain data mostly from passive samplers (Palmes tube or Ogawa badge) [8], but using these methods the dynamics of pollutant levels in a small timescale cannot be captured.

Within the frame of the research project “Smarter Transport” – IT for a co-operative transport system we performed field measurements on a fine spatiotemporal scale to investigate the daily profile and within-city differences in nitrogen-oxides (NO$_x$) in a medium-sized European city (Győr, Hungary). Two spatial scales were considered. At first, a single crossing was selected to gain reference data for canyoning. Secondly, three main roads were compared. Air samples were taken and compared to data of air quality monitoring stations and counted traffic data. In most cases significantly higher NO$_x$ exposures were obtained than monitoring data would suggest. The daily profile of traffic and nitrogen oxides concentration is in accordance. The canyon effect and significant within-city differences at both spatial scales were measured.
2 Methods

2.1 Study area

Győr is one of the most developed industrial cities in Hungary. It is situated in the western part of the Transdanubian region and has about 130,000 inhabitants. Although there is a bypass around the town, heavy traffic can be observed in the centre of the city, mainly along the road (Szent István Road) connecting Vienna and Budapest and some other main roads leading to the industrial area located in the north-eastern corner of the city (Figure 1). Since there are no industrial sources in the centre of the city and the prevailing wind comes from the north-west, emissions of nitrogen oxides are considered to originate primarily from road traffic (especially out of heating season).

Figure 1: Air sampling sites in Győr. Standard markers: S1–14 manual air sampling sites. Star-markers indicate the automata stations Győr 1 and 2, X: the investigated street canyon.
There are two monitoring containers in Győr providing continuous data about nitrogen oxides (besides other pollutants and basic meteorological data): Győr1. at the city centre on Szent István Road, Győr2. at the border of densely populated block building estates near Szigethy Attila Street (signed with stars on Figure 1).

2.2 Sampling and analysis

2.2.1 Single crossing study
A narrow crossing in the centre of Győr with heavy traffic (including a relatively high number of buses) was selected. Jókai Street is a one way street leading to the main road named after Szent István (Figure 2). There are no trees in the crossing altering wind flow. The road is surrounded by 4–5-storey buildings, so the building height street width ratio \( h/b \) is close to \( h/b = 2 \).

16 air sampling points were taken in the crossing (P1–16 in Figure 2), i.e. 8 sites with two elevations (1.5 m and 3 m) over the pedestrian area (0.5 m from the wall of the buildings). Air samples were pumped into Tedlar bags and transported to the laboratory for analysis.

![Figure 2: Plot of the investigated crossing. P1–16: air sampling points, F1–7: manual traffic counting sites, N1–3: noise measurement sites.](image)

Sampling was taken synchronously. The sampling day was an average workday in September 2013 (school time, out of heating season) at 5:30, 7:30, 11:30, 15:30, 18:00 and 22:50. Each sampling time was 8 minutes (1 l/min).

Manual traffic counting was conducted from 5:00 to 23:00 differentiating 6 vehicle categories in a half-hour time resolution and supplemented with separate counting during air sampling. Complementary, noise measurements were also taken [12].
2.2.2 Three main road study
Besides Szent István Road two other busy roads (Szigethy Attila and Fehérvári) were selected for comparison (Figure 1). 14 sampling sites were chosen. Samples were pumped into sampling bags from 1.5 m elevation two days after the crossing-study at the same times. Traffic and weather conditions were also similar. Manual traffic counting was performed at three sections: at air sampling points 3, 6 and 7 (see Figure 1).

All the samples were analysed in the laboratory of North Transdanubian Regional Environmental Protection and Nature Conservation Inspectorate on chemiluminescence based gas analysers (Thermo Environmental Instruments M-42C and Thermo Scientific M 42i).

3 Results

The six sampling times on both days were sufficient to capture the main character of the daily profile of NOx concentrations that we expected from long term data of the two monitoring containers. Nitrogen oxides levels had a sharp and high morning peak about 07.00 and 08.00 followed by the midday lull then a wider moderate plateau between 15.00 and 20.00.

3.1 Canyon effect

Our measurements could detect a canyon effect: as the angle of the wind direction and Jókai Street was mainly 0–60° (NNW to W), combinations of passage flow and eddies were observed. Each time remarkable differences of NOx concentrations were detected between locations, although there is no significant difference between the two investigated elevations (Wilcoxon signed rank test (SRT) p = 0.447, Figure 3(a)).

Figure 3:  Measured daily pollution. Centre of the spheres are at the sampling point and each radius is proportional to the sum of the 6 concentrations.
Significant differences between the left (P1, P2, P5, P6, P9, P10) and right side (P3, P4, P7, P8, P11, P12) of the crossing can be weakly demonstrated statistically (Wilcoxon SRT $p = 0.093$). The difference between the two streets of the crossing is insignificant (Jókai: P1-8 ↔ Szent Istvan (P9–16) $p = 0.944$).

3.2 Differences along and among main roads of Győr

Similar daily profiles were measured at each site (S1–14), although differences along all the three streets can be observed (Figures 5–6).
Figure 6: Comparison of measured NOx concentrations to other sampling sites and the nearest monitoring station along Szigethy Street.

There are outstanding differences between Szent István Road and Fehérvári Street in the point of averaged daily NOx levels of sampled sites along the roads (Mann-Whitney p = 0.0552) (Figure 7).

Figure 7: Box-and-whisker charts of the daily average measurement results along the three selected roads.
3.3 Traffic-pollution relation

Counted traffic flow data also show a typical daily profile. A morning peak in NO$_x$ concentration is precisely in accordance with the rush hour (Figure 8), proving that the main source of nitrogen oxides in Győr is indeed road traffic.

A more accurate detection of the afternoon peak would need a better temporal resolution.

![Figure 8: Temporal variation of counted traffic flow, sampled nitrogen oxide concentrations (mean of P7–9) and data from monitoring site Győr2.](image)

4 Discussion and conclusions

The characteristics of daily traffic flow profiles of Hungarian cities with a sudden morning peak and elongated afternoon plateau [13] are reflected by our counted data and also appear in the measured NO$_x$ profile. Sharper afternoon peaks were reported from other European and North American cities [11, 14, 15]. Our daily profiles and monitoring data support the fact that sampling times were chosen correctly, and our results can provide a reliable base for model validation.

Field measurements in a real street canyon confirm the importance of canyon effects and prove that they can cause significant differences inside a single street section or a crossing. An accumulation of pollution on the windward side of the street is often reported in model based studies [10] and wind tunnel effects [16, 17] were also detected in Jókai Street.

The origins of the differences observed along main roads are twofold. Firstly, differences in street geometry (e.g. squares, open spaces) and, on the other hand, the traffic flow is altered by connected roads.

In all the selected scenes, pedestrians and potentially exposed inhabitants can be observed. In the city centre, everyday offices (national tax office, court), bus stops and high schools can be found in the investigated area. Szigethy Street is
associated with highly populated building estates. Over the pedestrian area where our air samples were taken NO\textsubscript{x} concentration is mostly higher than regular monitoring data suggest. Therefore, personal exposures can be higher than reported.

A close relationship between counted traffic and measured pollutant concentration underpins that nitrogen oxides originate from road transport in urban environments. As the pollution increases almost on the spot, traffic management could be a solution to prevent sharp peaks of pollution.

**Acknowledgements**

This research was supported by research projects TÁMOP-4.1.1.C-12/1/KONV-2012-0017 „Green Energy” – Higher educational sector specific cooperation to improve rural economy in the field of energetics and TÁMOP-4.2.2.C-11/1/KONV-2012-0012: “Smarter Transport” – IT for co-operative transport system – The Project is supported by the Hungarian Government and co-financed by the European Social Fund. Authors are thankful for laboratory work to the North Transdanubian Regional Environmental Protection and Nature Conservation Inspectorate, especially to Péter Lautner and Ingrid Sándor.

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