23rd International Conference on
Harmonisation within Atmospheric Dispersion Modelling
for Regulatory Purposes
15-19 September 2025, Hamburg, Germany

EXTENDED ABSTRACT

Evaluation of Traffic-related Air Pollution Exposure in Sensitive Environments with a Gaussian Model and a Hybrid Eulerian-Gaussian Model

Matthias Karl, Chemistry Transport Modelling, Helmholtz-Zentrum Hereon, Geesthacht, 21502, Germany.
Email of first author: matthias.karl@hereon.de
Saba Manzoor, Earth Science and Engineering, Royal School of Mines, Imperial College London, London, SW7 2BP, United Kingdom.

Keywords: traffic emissions, particulate matter, nitrogen oxides, urban exposure, public health.

Abstract

Long-term exposure to traffic-related air pollution is a growing concern in cities worldwide. Vulnerable groups, such as children and the elderly, experience increased risks of respiratory illnesses like asthma due to prolonged exposure to nitrogen oxides and particulate matter from road traffic. This study establishes a framework to compare two urban dispersion models, the Gaussian model ADMS-Roads 5 and the hybrid Eulerian-Gaussian model EPISODE-CityChem, within an inner-city area of Hamburg. The framework ensures a robust comparison by using a common, high-resolution input dataset from an operational forecast system. Results show that in sensitive locations like schools, average $PM_{2.5}$ concentrations (9.9 - 11.1 µg/m³) exceed the WHO long-term exposure guideline of 5 µg/m³. On average, EPISODE-CityChem predicted 13 % higher $PM_{2.5}$ concentrations than ADMS. These findings underscore the necessity for granular spatial coverage when evaluating health risks in urban environments.

Introduction

Road traffic is a dominant source of air pollution in European cities, contributing significantly to emissions of nitrogen oxides (NO_x) and primary fine particulate matter ($PM_{2.5}$), which have serious implications for public health. Residents in urban areas with high traffic emissions face increased risks of asthma, lung cancer, and cardiovascular diseases. Health professionals are particularly concerned about vulnerable populations like children and the elderly (Carlsten *et al.*, 2011). Long-term exposure to NO_x is linked to severe health effects of the respiratory system (Hamra *et al.*, 2015).

In Hamburg, Germany, road traffic accounts for up to 30 % of outdoor $PM_{2.5}$ exposure in the city centre. This pollution also penetrates indoor environments, where traffic contributes 8 % to the $PM_{2.5}$ indoor exposure; an underestimated figure as it excludes tyre wear and road abrasion emissions (Borrego *et al.*, 2006, Ramacher and Karl 2020). This study assesses and compares traffic-related air pollution exposure using two dispersion models, ADMS-Roads 5 and EPISODE-CityChem, in an inner-city Hamburg area. ADMS-Roads is a Gaussian model optimized for high-resolution modelling along local road networks, while EPISODE-CityChem is a hybrid Eulerian-Gaussian model that captures pollutant transport, chemical transformation, and deposition on a 3-D grid, with embedded near-source dispersion capabilities.

Methods

Simulations for 2023 were performed with ADMS-Roads 5 (Carruthers *et al.*, 2001) and EPISODE-CityChem (Karl *et al.*, 2019), to assess the air quality in a 3.5 km × 2.8 km inner-city area. Both models were driven by a harmonised 2023 input dataset from Hamburg's operational urban air quality forecast system (urbanAQF; Karl *et al.*, 2024). The workflow (Figure 1) shows the exposure assessment with two urban dispersion models.

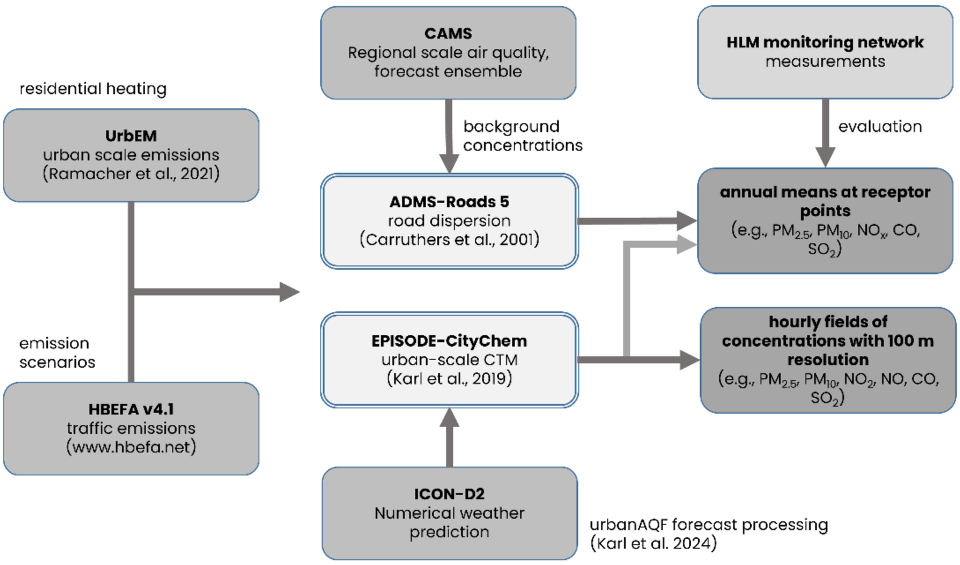

Figure 1. Workflow of the exposure assessment with two urban dispersion models.

ADMS-Roads calculated annual mean concentrations at specific receptor points. While EPISODE-CityChem used a Eulerian grid of 30 × 30 grid cells for Hamburg (1000 m resolution) and a sub grid with 100 × 100 m^2 cell size (including the receptor points) to determine hourly and annual mean concentrations. Road traffic emissions (tailpipe and non-exhaust) were calculated using the Handbook of Emission Factors for Road Transport (HBEFA) v4.1. The study area includes 376 receptors in sensitive environments (e.g., schools, hospitals, and nurseries) and four air quality monitoring stations. Receptors were sourced from the OpenStreetMap "Points of Interest" shapefile from Geofabrik.de. A Receptor point was included only if its distance to a road link was less than 200 m.

Model validation

Annual mean concentrations of NO_x, $PM_{2.5}$ and PM_{10} from both models were generally consistent with the measurements from the monitoring stations, with deviations within 50 %. Table 1 summarises the comparison of predicted annual mean concentrations with observations.

Table 1. Comparison of annual mean concentrations calculated by ADMS-Roads ("adms") and EPISODE-CityChem ("epicc") to measurements ("obs") at stations in the city centre of Hamburg. Station groups: "ubg" = urban background and "tra" = traffic.

Pollutant	Station	Mean (obs) [μg/m³]	Mean (adms) [μg/m³]	Mean (epicc) [μg/m³]	Delta (adms-obs)	Delta (epicc-obs)
NO_x	13 ST (ubg)	20.4	24.4	27.9	19 %	36 %
	64 KS (tra)	51.8	43.8	47.1	-15 %	-9 %
	17 SM (tra)	50.2	52.6	47.2	5 %	-6 %
	70 MB (tra)	47.5	55.0	57.7	16 %	21 %
$PM_{2.5}$	13 ST (ubg)	9.25	9.80	10.8	6 %	17 %
	64 KS (tra)	9.47	10.5	12.5	11 %	32 %
PM_{10}	13 ST (ubg)	13.4	13.5	17.1	1 %	28 %
	17 SM (tra)	16.5	15.9	20.4	-4 %	24 %
	70 MB (tra)	15.0	15.4	22.1	3 %	47 %

Exposure in sensitive environments

Figure 2 displays the NO_x and $PM_{2.5}$ concentration distributions and scatter at schools, hospitals and nurseries.

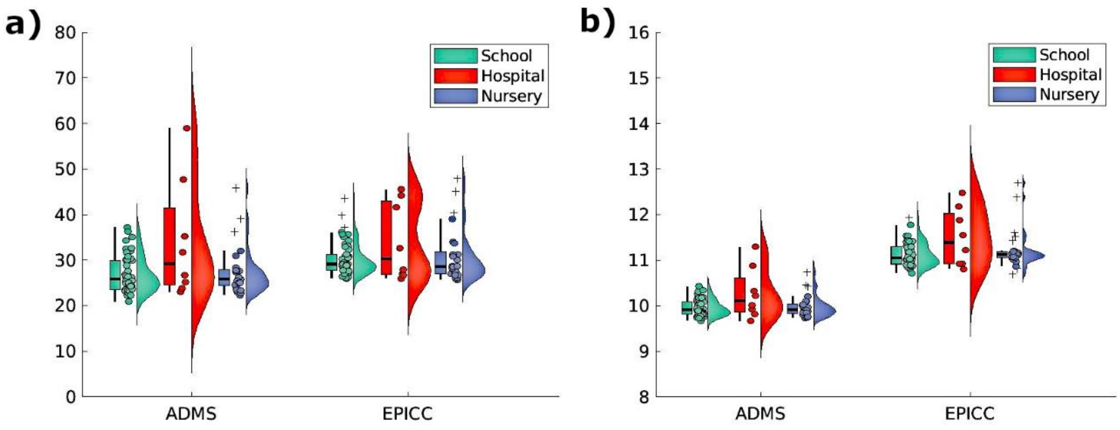

Figure 2. Half-violin plots of annual mean: a) NO_x (μg/m^3) from ADMS and EPISODE-CityChem and b) $PM_{2.5}$ (μg/m^3) from ADMS and EPISODE-CityChem, representing schools, hospitals and nurseries.

Hospitals had the highest levels of $PM_{2.5}$ exposure (ADMS: 10.3±0.6 µg/m^3; EPISODE-CityChem: 11.5±0.6 µg/m^3), a statistically significant finding (two-sample t-test; $p \leq 0.05$), likely due to their location near major roads for emergency access. While schools and nurseries had lower concentrations, their average $PM_{2.5}$ levels still exceeded the WHO long-term exposure guideline 5 µg/m^3.

Spatial distribution of exposure

The spatial distribution of NO_x and $PM_{2.5}$ is similar for both models, though EPISODE-CityChem generally predicts higher exposure (Figure 3). EPISODE-CityChem results consistently higher NO_x and $PM_{2.5}$ concentrations (12 % and 13 %, respectively, on average) than ADMS at receptors in sensitive environments. The highest concentrations for both models were found in the northeastern part of the area, where several hospitals and university buildings are located. Many schools near busy roads also experience elevated exposure. Average $PM_{2.5}$ concentrations (ADMS: 9.9±0.2 µg/m^3; EPISODE-CityChem: 11.1±0.3 µg/m^3) at schools (in total 50) are close to the revised EU ambient air quality limit of 10 µg/m^3 (AAQD 2024/2881).

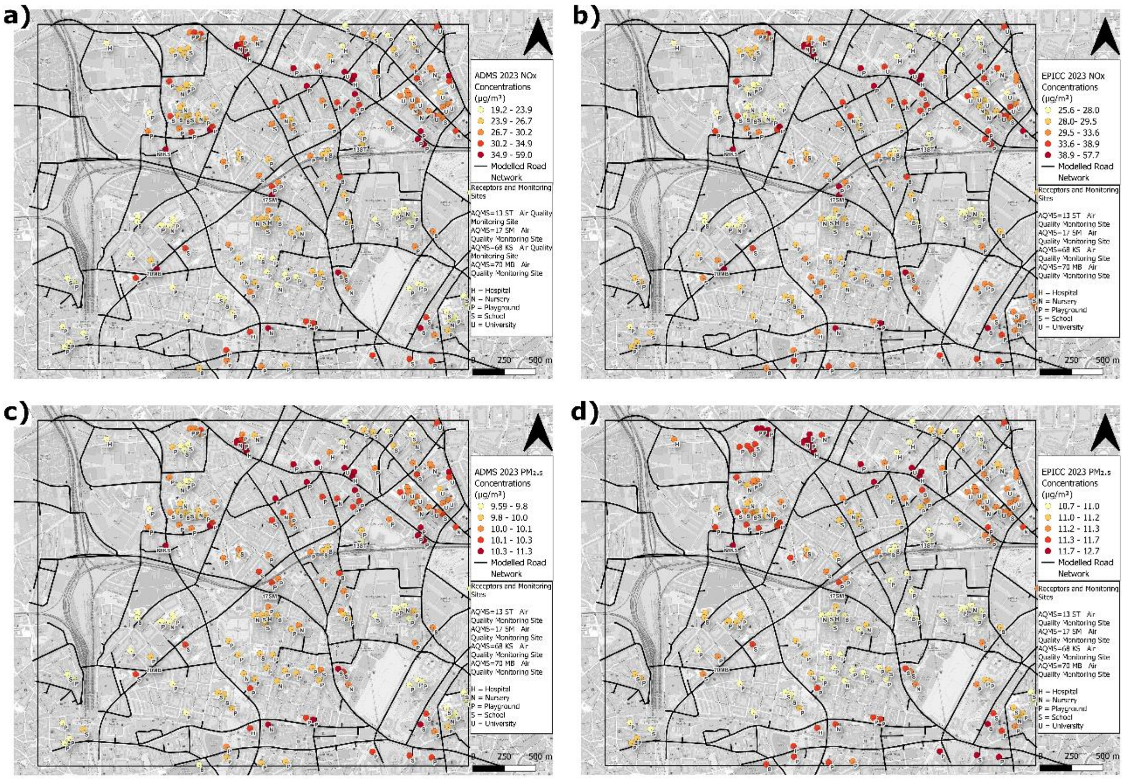

Figure 3. Maps of annual mean concentrations at inner-city receptors from both models: a) NO_x from ADMS; b) NO_x from EPISODE-CityChem; c) $PM_{2.5}$ from ADMS; and d) $PM_{2.5}$ from EPISODE-CityChem. Receptor points are labelled with type (H, N, P, S, U). Note the different colour scales for the two models; however, the spatial gradient can be compared because the same frequency distribution was used for the colour bins.

Conclusions and outlook

The study established a framework to compare urban dispersion models, validated against data from official air quality monitoring stations. Consistency and robustness were ensured by a common, high-resolution input dataset from Hamburg's operational urban air quality forecast system. This allows reliable assessment of pollution relative to EU Air Quality Directive limits. Our findings have significant public health implications because $PM_{2.5}$ levels in sensitive locations such as schools and hospitals are above WHO guidelines. The more complex model, EPISODE-CityChem, consistently predicted higher $PM_{2.5}$ levels, suggesting simpler models could be underestimating health risks. Results emphasise the need for advanced, high-resolution modelling for accurate health risk assessments and guide targeted urban planning.

A key objective is developing a standardised evaluation protocol for assessing exposure in sensitive environments. This protocol will underpin future uncertainty analyses, improving confidence in exposure estimates across different dispersion approaches. The next project phase will apply both models to simulate future mobility scenarios, assessing strategies to achieve zero emissions of air pollutants and greenhouse gases. This provides evidence-based support for urban planning and climate policy by evaluating potential outcomes and their associated uncertainties.

Acknowledgements

This project uses data from urbanAQF: https://hcdc.hereon.de/urbanaqf.

References

Borrego, C., Tchepel, O, Costa, A.M., Martins, H., Ferreira, J., and A.I. Miranda. (2006), "Traffic-related particulate air pollution exposure in urban areas". *Atmospheric Environment*, Vol. 40, pp. 7205-7214.

Carlsten, C., Dybuncio. A., Becker, A., Chan-Yeung, M., and M. Brauer. (2011), "Traffic-related air pollution and incident asthma in a high-risk birth cohort". *Occupational and Environmental Medicine*, Vol. 68, pp. 291-295.

Carruthers, D.J., Dickson, P., McHugh, C.A., Nixon, S.G., and W. Oates. (2001), "Determination of compliance with UK and EU air quality objectives from high-resolution pollutant concentration maps calculated using ADMS-Urban". *International Journal of Environment and Pollution*, Vol. 16, pp. 460-471.

Hamra, G.B, Laden, F., Cohen, A.J., Raaschou-Nielsen, O., Brauer, M., and D. Loomis. (2015), "Lung Cancer and Exposure to Nitrogen Dioxide and Traffic: A Systematic Review and Meta-Analysis". *Environmental Health Perspectives*, Vol. 123, pp. 1107-1112.

Karl, M., Walker, S.-E., Solberg, S., and M.O.P. Ramacher. (2019), "The Eulerian urban dispersion model EPISODE - Part 2: Extensions to the source dispersion and photochemistry for EPISODE-CityChem v1.2 and its application to the city of Hamburg". *Geoscientific Model Development*, Vol. 12, pp. 3357-3399.

Karl, M., Acksen, S., Chaudhary, R., and M.O.P. Ramacher. (2024), "Forecasting system for urban air quality with automatic correction and web service for public dissemination". *International Journal of Digital Earth*, Vol. 17, pp. 1-22, doi:10.1080/17538947.2024.2359569.

Ramacher, M.O.P. and M. Karl. (2020), "Integrating Modes of Transport in a Dynamic Modelling Approach to Evaluate Population Exposure to Ambient NO_2 and $PM_{2.5}$ Pollution in Urban Areas". *International Journal of Environmental Research and Public Health*, Vol. 17, 2099, pp. 1-35.