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EXTENDED ABSTRACT

Statistical modelling of impact of COVID-19 restrictions to outdoor air quality in Estonia and Latvia

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Introduction

It is known from several studies that urban concentration of nitrogen dioxide was reduced significantly worldwide during COVID-19 restrictions due to a decrease in the number of cars, trucks, and buses on the streets. Reduction of NOx is more prominent than of other pollutants, such as SO_2, CO and particulate matter, which originate from more diverse sources (Sokhi et al., 2021).

The impact of COVID-19 restrictions on concentrations of nitrogen dioxide in urban centres in Estonia and Latvia is analysed, comparing data from (1) years of pandemic 2020 and 2021, and (2) years before the pandemic 2017, 2018 and 2019. Air quality monitoring data in capital cities of Estonia and Latvia, respectively Tallinn (monitoring stations Rahumäe, Liivalaia and Õismäe) and Riga (stations Parks and Kengarags) are used. In addition, smaller cities Tartu, Kohtla-Järve and Narva in Estonia were studied, as each of them has one urban monitoring station. This study aims to understand and quantify the differences between COVID-19 restrictions and time intervals of usual (non-restricted) regime. Statistical model, based on multi-linear regression, was used to eliminate the noise due to changing weather patterns, thus refining the signal of reduced human activities on air quality.

In Riga, the air quality data from first and second COVID-19 restriction periods (springs of 2020 and 2021) have been so far compared with non-restricted time of these years and significant reduction of concentrations of NO_2 was found, but not for PM_{10} and $PM_{2.5}$ (Steinberga and Truhnevics, 2022). The concentrations of gaseous pollutants and particulate matter in comparison of first restriction period (2020) and equivalent time intervals in 2016 – 2019 in Tallinn and Tartu were studied in within a worldwide comparative study (Sokhi et al., 2021), with rather similar results.

This study is targeted at understanding the similarities and differences, based on unified and fit-for-purpose methodology, in urban air quality in Estonia and Latvia, two countries in Eastern Baltic region, in periods of COVID-19 restrictions.

Data and methods

The data from Riga (605000 inhabitants) originate from two regular monitoring stations: Parks (a small park in city centre) and Kengarags (in an area of block houses, near a major traffic street). Three stations are located in Tallinn (462000 inhabitants): Liivalaia (major traffic street), Rahu (urban-industrial) and Õismäe (urban background). Each of Estonian towns Tartu (98000), Narva (53000) and Kohtla-Järve (33000) have one monitoring station. Narva and Kohtla-Järve are urban-industrial sites, as thermoelectric power plants and chemical industries are located nearby. Although the monitoring stations provide data with hourly resolution, this analysis is based on weekly concentrations, to eliminate the daily and weekly courses of anthropogenic sources. As NO and NOx data are not available for Riga, only the concentrations of NO_2 were considered.

Both in Estonia and Latvia the COVID-19 measures were milder than in many European countries, thus term “restrictions” (not “lockdown”) is used. In most severe restriction periods the schools, universities, most of offices, as well as shops were closed, except food stores. Public events were cancelled, most of public transport did not operate, but walking outdoors and driving was not forbidden. Most of industries operated. Both in Estonia and Latvia the severe restrictions took effect first time in a few days after WHO declared pandemic on March 11, 2020, and were partially relaxed from beginning of May. Nearly the same dates apply for second restriction period in 2021. In this study the weeks 12 – 18 are considered restriction periods in both years. Although partial restrictions, e.g. ban of big public events, remained for entire period of pandemic, their effect to people´s mobility and traffic was minimal. Thus, the rest of time in 2020 – 2021 was considered “business as usual”. For comparison, the data from 2017 – 2019 were analysed.

It is evident that weather affects the urban air pollution in many ways. In first stage of this study the simple linear correlations of NO_2 versus ambient temperature, wind speed and vertical temperature gradient in surface were found essential. The temperature and wind speed data in Estonia for each air quality monitoring site originate from the nearest observation site of national weather monitoring system (https://www.ilmateenistus.ee/kliima/ajaloolised-ilmaandmed/) and in Latvia from automated station within Riga city, operated by University of Latvia. The data on vertical temperature gradient for entire region originate from one site, Külitse meteorological mast Near Tartu, operated by Estonian Environmental Research Centre (EERC), where temperatures at heights of 2 – 24 m are measured. As the temperature gradient is mainly driven (besides daily course) by pattern of cyclones and anticyclones, which are much bigger than the nearly 200 km distance to the most far-away stations, use of one single high-quality dataset is justified in absence of measurements closer to each monitoring station.

As weather patterns significantly affect urban air quality through ambient temperature, wind speed and vertical temperature gradient in surface layer, a multi-linear regression model based on these variables was applied to the concentration of NO_2. Then the regression residuals were studied, considering that after elimination of weather impact, the assumed reduction of NO_2 in restriction periods is more pronounced. Welch Two Sample t-test, which is appropriate for unequal dispersions and unequal sample sizes (such as weeks with COVID-19 restrictions and rest of the year), was applied to estimate the significance of differences in mean concentrations.

Results

It was found that higher ambient temperature and stronger wind have negative (decreasing) impact to NO_2 concentration (an example in Figure 1) and vertical temperature gradient has positive (increasing) impact (Figure 2) on it. It is evident that low outdoor temperature correlates with residential heating emissions. Strong wind dilutes the pollutants and blows them away from urban areas, and thermal inversion causes accumulation of pollutants in surface layer. Thus, the weather characteristics closely related to NO_2 level are explained by known physical mechanisms. Vertical temperature gradient is positively correlated with concentrations in most of cases (see example in Figure 3), as positive gradient (i.e. thermal inversion) makes dispersion conditions worse, suppressing the vertical convective transport.

However, the effect of temperature to the concentration of NO_2 is more pronounced, in terms of linear correlation, compared to wind speed and temperature gradient. That strong relation refers to importance of heating emissions and is possibly also related to the fact that in summertime there are less cars driving within the city, due to vacations. Most of weather dependences in 2020 appear weaker than in year before and after, which may be a result of extraordinary mild winter and cold spring, which made the annual course of weather parameters smaller, but effects of pandemic might alter the seasonal variations, too.

The multi-linear regression of weekly average NO_2 concentrations *versus* ambient temperature, wind speed and surface-layer vertical temperature gradient, as independent variables, appears statistically significant at confidence level of minimum 99% in all stations (Table 1).

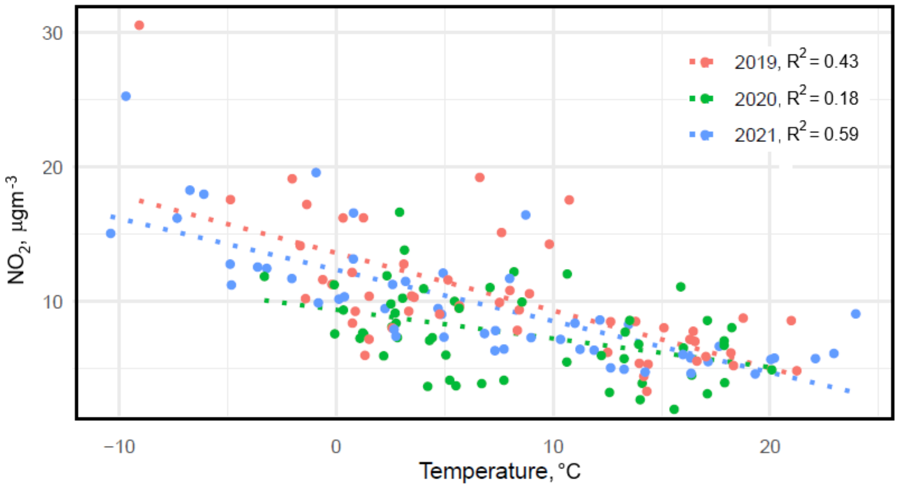

Figure 1. Linear regression of weekly average concentrations of NO_2 in Tartu *versus* ambient temperature.

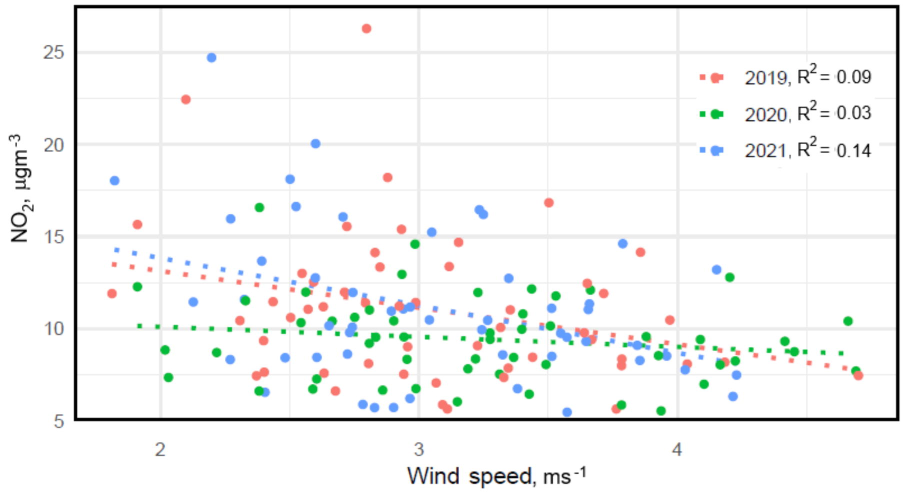

Figure 2. Linear regression of weekly average concentrations of NO_2 in Tallinn-Rahu *versus* wind speed.

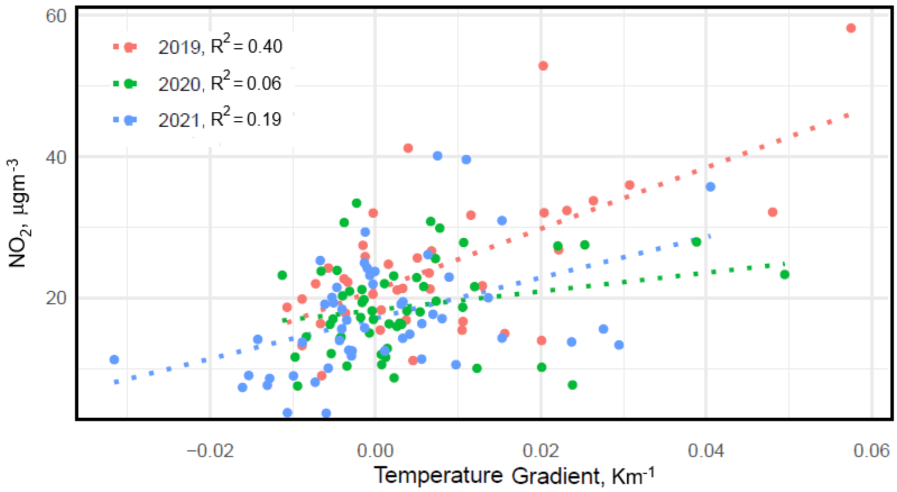

Figure 3. Linear regression of weekly average concentrations of NO_2 in Riga-Parks *versus* surface-layer vertical temperature gradient.

Table 1. Coefficients of multi-linear regression. The assumed units are: K for temperature, ms^{-1} for wind speed, hPa for atmospheric pressure and Km^{-1} for vertical temperature gradient. Statistical significance: * at 95% confidence level, ** at 99% confidence level and *** at 99.9% confidence level.

	(Intercept)	Temperature	Wind speed	Temp. gradient
Tartu	20.7***	-0.530***	-2.440**	135.7***
Narva	17.8***	-0.326***	-2.139***	60.2***
Kohtla-Järve	12.7***	-0.229***	-1.535***	48.9***
Tallinn-Rahu	26.6***	-0.404***	-3.669***	85.9***
Tallinn-Õismäe	23.1***	-0.389***	-3.643***	111.7***
Tallinn-Liivalaia	45.9***	-0.546***	-5.374***	137.0**
Riga-Parks	44.4***	-0.540***	-6.936***	137.0***
Riga-Kengarags	43.8***	-0.962***	-4.281***	176.7***

The residuals of multilinear regression are expected to present the impact of COVID-19 restrictions in more pure form than "raw" concentrations, as the linear dependence on key meteorological parameters is eliminated. An example of residuals of linear regression by weeks and years is given in Figure 4. Most of the weekly residuals in 2020 and 2021 are well below the zero-line, which means that the respective pollution levels are lower than expected by weather-based regression line.

Based on Welch t-test, the regression residuals show statistically significant reduction in all monitoring stations, except Riga-Kernarags, in comparison between restriction periods (altogether 14 weeks in 2020 and 2021) and equivalent weeks extracted from 2017-2019 (Table 2). The most prominent reduction (by 20-30%) was found in Riga-Parks, which is located in centre of the biggest city under consideration. No significant differences between non-restricted periods in years of pandemic (2020 and 2021) and equivalent periods in 2017-2019 were found in any of sites studied.

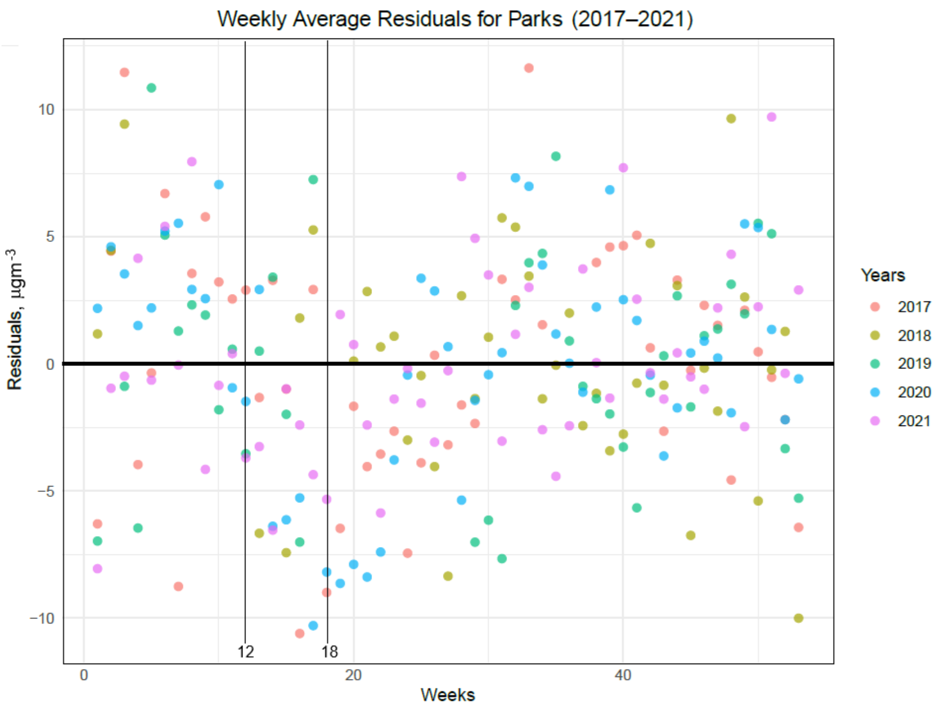

Figure 4. Residuals of multi-linear regression for Riga-Parks monitoring station. Interval of restriction weeks (12 – 18) in 2020 and 2021 is marked with black vertical lines.

Table 2. Results of Welch Two Sample t-test: means of multi-linear regression residuals of NO_2 (μgm^{-3}) and respective p-values. Statistically significant p-values at minimum 95% level are marked in bold font.

Monitoring site	Restricted weeks in 2020-2021 *vs.* equivalent weeks in 2017 - 2019			Non-restricted weeks in 2020-2021 *vs.* equivalent weeks in 2017 - 2019		
	2020-2021	Equivalent	p-value	2020-2021	Equivalent	p-value
Tartu	-4.27	1.03	**$2.7 \cdot 10^{-5}$**	0.27	-0.08	0.49
Narva	-1.54	0.43	**0.0092**	0.09	-0.03	0.47
Kohtla-Järve	-1.13	0.68	**0.0034**	0.07	-0.06	0.52
Tallinn-Rahu	-3.33	0.50	**0.0001**	0.21	0.04	0.52
Tallinn-Õismäe	-3.44	0.19	**0.0083**	0.22	0.02	0.57
Tallinn-Liivalaia	-5.80	6.03	**$9.2 \cdot 10^{-6}$**	0.37	-0.49	0.28
Riga-Kengarags	-5.21	-2.51	0.094	0.35	0.19	0.74
Riga-Parks	-6.79	-0.59	**0.0013**	0.46	0.05	0.40

Discussion and conclusions

Results presented in Table 2 show that mean NO_2 concentrations in in seven out of eight urban monitoring stations Estonia and Latvia in weeks of severe COVID-19 restrictions were lower than during equivalent weeks in three years before, with statistical significance at least at 99% confidence level. In contrary, the “nearly-normal” weeks in COVID-19 years and equivalent weeks in three years before do not present statistically significant differences in mean concentrations in any of stations (see Table 2). Thus, the statistical model based on elimination of weather impacts with multi-linear regression works and gives quantitative results on reduction of urban NO_2 pollution in the region under consideration. Failure to prove statistical significance in Riga-Kernarags, obviously due to low concentrations in early springs of previous years, needs further clarification.

Dramatic reduction of urban traffic flows in COVID-19 restriction period was a “natural experiment”, a kind of simulation for possible future developments, such as replacing a large part of vehicles with electric ones, which don´t emit nitrogen oxides. The example of Estonia and Latvia shows improvement of air quality in medium-sized and small towns.

Acknowledgements

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