ABSTRACT

The extreme traffic measures during the COVID-19 lockdown provided a unique opportunity to gain better insight into the relationship between traffic characteristics and NO$_2$ concentrations in Maribor, a small Slovenian city. NO$_2$ traffic and meteorological data were statistically processed in detail for March and April 2018, 2019 and 2020 to get a historical insight and to exclude the specifics of the lockdown period. The extreme event resulted in an average reduction of road traffic of 42%. The decrease in the number of passenger cars ranged from 33.9 to 60.3% per day with the largest decrease on the motorway. Daily averages of heavy goods traffic declined on the motorway and the expressway by 24.6% and 7%, respectively. Traffic characteristics were reflected in a 24–27% decrease in NO$_2$ concentrations at the urban station. The change is smaller than the change in traffic volume, which could be explained by the change in the composition of the vehicle fleet due to the increase in NO$_2$-dominant traffic sources, e.g. diesel heavy goods vehicles. The presented results are relevant for improving air quality and sustainable mobility management in small cities. They highlight the important role of reorganisation of heavy goods traffic in urban logistics.

KEYWORDS
road traffic; extreme event; COVID-19 lockdown; NO$_2$ emissions; meteorological conditions; air pollution.

1. INTRODUCTION

Emissions from road transport have been identified as the main source of ambient air pollution in Slovenian urban areas as well as worldwide, especially in European and North American cities [1–6]. Many documents emphasise that air pollution is a major health problem for the world population, as 55% of the world population lives in urban areas [7–13]. The transport sector is responsible for most of the emissions of nitrogen oxides (NO$_x$) – 47% [14], which can affect liver, lung and spleen functions and blood quality [15–16]. Long-term exposure to nitrogen dioxide (NO$_2$) has been linked to a wide range of serious health problems such as hypertension, diabetes, heart and cardiovascular disease and even death [17]. Furthermore, these gases contribute to the formation of acid rain and tropospheric ozone (O$_3$) as well as to the eutrophication of water and soil [1, 18, 19].

In recent decades, significant progress has been made in understanding the relationship between transport emissions and urban air quality. Nevertheless, there are still some open questions. These are due, on the one hand, to insufficient knowledge of pollutant formation and transport connected to a deficient air quality monitoring network, and, on the other hand, to assessment of pollutant emissions from vehicles, which is based on numerous assumptions. Pollutant concentrations depend on the type of pollutant, sources, sinks and meteorological conditions related to turbulence and advection of wind, air temperature and humidity [20, 22]. Data are usually obtained from a small number of stationary reference stations, which are not well suited for monitoring the local spatial variability of pollutants in ambient air and for exposure studies of the population. Various methods have been developed to fill the described gaps. An overview of current regional and local air quality modelling practices in Europe was prepared by Thunis et al. [23].

Extreme events can provide a better insight into the complex formation and transport processes of air pollutants. This is the case with the COVID-19 pandemic declared on 11 March 2020 [24]. The restriction of human activities during the COVID-19 lockdowns resulted in a considerable improvement
in air quality worldwide, which was mainly due to the decrease in traffic [25–35]. In large cities such as Ankara and Istanbul (Turkey) during the lockdown, public transportation usage dramatically decreased by more than 80% by the end of March and did not change significantly until the end of May [36]. For pollutants mainly related to road traffic, the decrease was greater, especially for NO₂. Its concentrations were reduced by 25–60%; in Barcelona, Rome and Valencia by 51–53% [37, 38]. The data presented are mainly related to metropolitan areas and large cities. As far as we know, the detailed studies of the effects of traffic volume on NOₓ concentrations have not been carried out for small cities (with 50,000 to 100,000 inhabitants), which account for about half of all cities in Europe and where 30% of city dwellers live [39].

The above-mentioned facts gave rise to a detailed study of the effects of traffic on NOₓ concentrations during the extreme event of the COVID-19 lockdown from 15 March to 15 May 2020 in the city of Maribor, Slovenia, with 110,000 inhabitants. Lockdown measures stopped/restricted public transport, restricted motorised traffic, kept people in their homes and away from non-essential shops and closed educational institutions. Analysing the impact of lockdown measures on environment that are extremely rare in practice and therefore can only be modelled in research allows us to get a realistic picture of how we can contribute to urban air quality by limiting traffic.

As in many other cities, cars are the predominant mode of transport in Maribor, even for short distances, while air pollution, noise, public health, road safety and parking remain key issues for the city and present challenges for the new transport strategy adopted in 2015 [40]. Although it is clear that polluted air and passive mobility have negative effects on the health of citizens, the health of the population is not yet considered in the debate on transport policy. In the context of developing a new transportation strategy, workshop participants ranked transportation challenges to improve air quality only ninth out of ten [40]. This requires effective tools to promote the use of sustainable transport as well as awareness and training for the entire community. In addition, spatial planning must be equally considered in the context of land use and urban structure.

The purpose of this study was to gain better insight into the relationship between road traffic characteristics and air quality in order to help policy makers take more effective steps to improve the quality of life in the city and to encourage the use of sustainable mobility. The following questions helped form the research aims:

- How did the NO₂ concentrations at the urban monitoring station and the background monitoring station vary during the extreme event, and what was their reduction?
- How are the NO₂ concentrations at two monitoring stations related to each other and to meteorological parameters?
- How did traffic volumes change for passenger cars, heavy goods vehicles and all vehicles on different categories of roads (e.g. the motorway, expressway, primary, secondary and tertiary roads) and what was the composition of the vehicle fleet during the extreme event?
- What is the relationship between traffic data and NO₂ concentrations along a major arterial road and in the background?

The first aim of our study was to determine the effects of traffic on NO₂ concentrations during the extreme lockdown event compared to historical data (years 2018 and 2019) and considering the variations in emissions and meteorological conditions in a small city. On the basis of previous studies, the hypothesis has been put forward that road traffic is the dominant source of NO₂ in Maribor and also the dispersion process of this pollutant in ambient air [1, 41]. Positive and negative correlations between meteorological variables and NO₂ were discussed based on studies in urban areas in Banja Luka, BH [42, 43], and results from Masey et. al [44]. The second aim of our study was to gain additional knowledge about the formation and transport of NOₓ in ambient air, which could be relevant not only for the air quality and sustainable mobility management of the city of Maribor, but also for other cities with similar conditions, especially in the European post-communist countries.

2. METHODOLOGY

2.1 Study site

Maribor is the second largest city in Slovenia. It is in the country's north-east region in the Drava River basin, which is open to south-east (Figure 1). The city centre lies north of the Drava, while the industrial, shopping and residential areas are south of the river. The Maribor area has a moderate continental climate with strong
therefore about 42,000 people from other municipalities migrate to the city every day [46]. Passenger cars are their predominant means of transport.

The residents of MOM are not exposed to a higher health risk due to poor air quality. Most problems are caused by exceeding the limit/target values for PM$_{10}$ and O$_3$, which are formed by photochemical reactions from precursors, among which NO$_x$ are the most common [47]. The annual and hourly limit values for NO$_2$ have not been exceeded in recent years, nor has the critical annual value for NO$_x$. NO$_2$/NO$_x$ concentrations are higher in winter due to their reduced conversion into O$_3$ and addition sources (e.g. heating system).

2.2 NO$_2$ and meteorological data

Hourly NO$_2$ and meteorological data were obtained for the years 2018, 2019 and 2020. In MOM and its surroundings there are 5 stationary reference stations for monitoring air quality (Figure 1). The hourly NO$_2$ concentrations are measured at two sites, Maribor center and Tezno, using the reference method (SIST EN 14211) based on chemiluminescence [47]. The first station is located along a main traffic artery (e.g. primary road) in a wide street canyon within the so-called commercial residential area in the city centre. It has been in operation since 1992 and is characterised as an...
urban station reflecting the effects of road traffic on NO$_2$ concentrations. The latter station has only been in operation since January 2020. It is located within the residential area more than 400 m and 1000 m from the primary road and motorway, respectively. Previous studies [47, 48] showed that NO$_3$ concentrations fall to urban background levels about 200 m from a motorway. Therefore, the stationary reference station Tezno is considered as an urban background station in our study.

Data on air temperature at a height of 2 m, relative humidity, air pressure, precipitation and wind speed and direction at a height of 10 m were obtained from the meteorological station Skoke meteo (Figure 1) of ARSO (Environmental Agency of the Republic of Slovenia), which is representative for the study site [45].

2.3 Traffic data

There are 13 traffic counting stations in MOM, which are part of the Slovenian national road network. Our study refers to 9 counting stations: two on the motorway (Ptujska AC, Malečnik AC), the expressway (Maribor HC and Meljška HC), the primary road (MB Ptujska and Brestnica) and the secondary road (Laznica, Dogoše) and one on the tertiary road (Celestria; Figure 1), which were purchased by DARS (the Slovenian motorway company). The traffic counting stations are equipped with two types of automatic vehicle counters called QLTC-8 or QLTC-10. Both types distinguish 10 different categories of vehicles and count the following data: all vehicles, motorcycles, passenger cars, buses, light commercial vehicles (less than 3.5 tonnes), medium commercial vehicles (3.5 – 7.0 tonnes), heavy commercial vehicles (over 7.0 tonnes), trucks with one trailer, trucks with several trailers and nominal axle load. The traffic volume was observed at a given location in both directions (the data are separated for each direction and also summed). Our study analysed data from passenger cars, heavy goods vehicles and all vehicles for the years 2018, 2019 and 2020. The data were sorted by road type (subsection 2.1.). The data from the traffic counting stations MB Ptujska and Meljška HC were analysed in detail, as they are closest to the stations monitoring air quality.

2.4 Data processing

NO$_2$, traffic and meteorological data were statistically processed for the years 2018 and 2019 to get a historical insight. They were analysed in more detail for March and April 2018, 2019 and 2020 to exclude the specifics of the extreme event of the COVID-19 lockdown. The variations of the parameters were evaluated and their relative change (%). Classical statistical calculations and linear regression analyses were performed with Statistica 13 (StatSoft Inc., Tulsa, OK, USA) to test the statistical significance between different parameters and groups. A value of $p<0.05$ was considered significant. The results were interpreted using a Pearson correlation coefficient ($\rho$) as shown in Table 1.

Sometimes technical problems occurred during the continuous measurement of the investigated parameters. In such examples, data was lost for a few hours or perhaps the whole day. Such blank spots were eliminated and not considered in the further analysis.

### Table 1 – Scale for determining the strength of the associated variables

| $\rho$ value | Strength of association |
|-------------|--------------------------|
| 0.00        | No association           |
| 0.01 – 0.19 | Slight association       |
| 0.20 – 0.39 | Weak association         |
| 0.40 – 0.69 | Moderate association     |
| 0.70 – 0.89 | Strong association       |
| 0.90 – 0.99 | Very strong association  |
| 1.00        | Complete association     |

3. RESULTS AND DISCUSSION

The hourly NO$_2$ concentrations at the urban site before and after the extreme event of the COVID-19 lockdown are shown in Figure 2 together with the vehicle numbers at the Meljška HC counting station. For the same period, they are compared with the data from 2018 and 2019. After the strict lockdown measures a large change of the investigated parameters can be observed on 21 March 2020, which is supported by statistical analyses of NO$_2$, traffic and meteorological data.

The statistical characteristics of the key data analysed during the lockdown event are presented in Table 2. The average values did not shift significantly between two meteorological and traffic counting stations. Therefore, it can be assumed that in the city of Maribor the hourly NO$_2$ concentration and air temperature averaged 20.9 $\mu$g/m$^3$ and 9 °C, respectively, while the average volume of passenger cars on the primary roads was 445. Compared to the same periods in 2018 and 2019, during the
lockdown event the average NO₂ concentration in March and April decreased by 25% and 22–33%, respectively (Table 3). The average air temperature, air pressure and wind speed have not deteriorated significantly compared to previous years, but this is not the case for precipitation. Average precipitation was about 48% and 53% lower in March and April 2020, respectively, which is most likely reflected in a relative humidity value about 15% lower (Table 3).

Table 2 – Statistical characteristics during the COVID-19 lockdown

|                         | Maribor Center | Maribor Tezno | TV–PC MB Ptujška | TV–PC Meljska HC |
|-------------------------|----------------|---------------|------------------|-----------------|
| Population              | 1205           | 1205          | 1205             | 1205            |
| Median                  | 16.55          | 15.24         | 8.15             | 337.00          |
| Mode                    | 12.10          | 11.46         | 7.45             | 17.00           |
| St. deviation           | 13.36          | 17.33         | 6.45             | 407.67          |
| Minimum                 | 2.70           | 0.00          | -4.95            | 4.00            |
| Maximum                 | 98.50          | 111.00        | 25.05            | 2219.00         |
| Average                 | 20.01          | 21.76         | 8.96             | 437.17          |

Table 3 – Weather and NO2 data during observed time period

|                      | Air pressure [hPa] | Air temperature [°C] | Rel. humidity [%] | Precipitation [mm] | Wind speed [m/s] | NO₂* [μg/m³] |
|----------------------|-------------------|---------------------|------------------|--------------------|-----------------|--------------|
| March 2018           | 975.6             | 3.5                 | 77.2             | 61.1               | 2.9             | 31.2         |
| March 2019           | 987.3             | 8.2                 | 63.4             | 51.0               | 3.1             | 31.0         |
| March 2020           | 986.4             | 6.7                 | 65.5             | 29.0               | 3.1             | 23.3         |
| April 2018           | 984.1             | 14.7                | 64.0             | 66.9               | 3.3             | 22.0         |
| April 2019           | 983.3             | 11.2                | 68.8             | 79.6               | 2.8             | 25.5         |
| April 2020           | 986.7             | 11.6                | 56.3             | 34.6               | 2.6             | 17.2         |
| Year 2018            | 985.3             | 11.6                | 75.0             | 927.6              | 2.3             | 22.0         |
| Year 2019            | 984.8             | 11.8                | 74.0             | 1023.6             | 2.4             | 25.0         |

*The parameter was analysed only for the Maribor center monitoring station, as the Tezno monitoring station has only been in operation since January 2020.
expressway and primary/secondary/tertiary roads, respectively (Table 4A). As expected, the decline in heavy goods traffic was much smaller. Their daily averages fell on the motorway followed by a primary road and the expressway by 24.6% and 7%, respectively (Table 4B). On other type of roads, the decrease ranged from -3 to 16.1%. The data discussed reflect the general fleet composition during the lockdown period. Traffic decreased in the range between 32.2 – 51.7%, mainly on the motorway (Table 4C) or by 42% on average.

Figure 3 focuses on daily averages of NO\textsubscript{2} concentrations in the city centre in the periods before and during the lockdown event and daily data from two traffic counting sites (Meljska HC and MB.

Table 4 shows the average daily traffic volume for passenger cars (A), heavy goods vehicles (B) and all vehicles (C) on 9 selected roads (subsection 2.3) in 2018 and 2019 and in the period March–April 2018, 2019 and 2020. The first column is an ID number of the counting station (No.), the second is its name (TC name), followed by the type of road and the traffic volume for the respective period. A reduction in traffic during the lockdown event is calculated as an average of the years 2018 and 2019 compared to 2020. The decrease in the number of passenger cars ranged from 33.9 to 60.3% per day. The largest decrease was recorded on the motorway with 56.4 to 60.3%, while the range was similar on other roads: 33.9 – 43.9% and 39.5 – 44.6 on the

Table 4 – Average daily traffic volume data during observed time period

| No. | TC name   | Road type | 2018 | 2019 | 2018 | 2019 | Lockdown reduction (%) |
|-----|-----------|-----------|------|------|------|------|------------------------|
| 840 | Ptujska AC| Motorway  | 25668| 27710| 30864| 31656| 56,38                  |
| 889 | Malečnik AC| Motorway | 20393| 21493| 23237| 25538| 60,31                  |
| 15  | Maribor HC| Express   | 26470| 27491| 25426| 26467| 33,86                  |
| 16  | Meljska HC| Express   | 19180| 20312| 19153| 19910| 43,94                  |
| 19  | MB Ptujska| Primary   | 18884| 19452| 19209| 19030| 42,47                  |
| 61  | Brestrnica| Primary   | 7568 | 7925 | 7583 | 7772 | 44,50                  |
| 706 | Laznica   | Secondary | 8681 | 8969 | 7662 | 8670 | 40,23                  |
| 342 | Dogoše    | Secondary | 10424| 9945 | 10014| 39,50 |                      |
| 488 | Celestrina| Tertiary  | 3306 | 3440 | 3206 | 3249 | 44,65                  |
| 840 | Ptujska AC| Motorway  | 7066 | 7396 | 7067 | 7119 | 24,41                  |
| 889 | Malečnik AC| Motorway | 6739 | 7047 | 6660 | 6760 | 24,89                  |
| 15  | Maribor HC| Express   | 793  | 809  | 785  | 812  | 8,61                   |
| 16  | Meljska HC| Express   | 469  | 530  | 491  | 500  | 5,51                   |
| 19  | MB Ptujska| Primary   | 575  | 579  | 590  | 550  | 24,61                  |
| 61  | Brestrnica| Primary   | 304  | 315  | 322  | 326  | 10,18                  |
| 706 | Laznica   | Secondary | 153  | 214  | 148  | 170  | 4,09                   |
| 342 | Dogoše    | Secondary | 14   | 17   | 16   | 16   | 16,13                  |
| 488 | Celestrina| Tertiary  | 37979| 40618| 43826| 44769| 49,53                  |
| 840 | Ptujska AC| Motorway  | 31653| 33330| 37020| 37350| 51,75                  |
| 889 | Malečnik AC| Motorway | 31653| 33330| 37020| 37350| 51,75                  |
| 15  | Maribor HC| Express   | 29345| 30531| 28228| 29479| 32,18                  |
| 16  | Meljska HC| Express   | 21342| 22653| 21373| 22225| 41,85                  |
| 19  | MB Ptujska| Primary   | 21399| 22040| 21811| 21560| 40,97                  |
| 61  | Brestrnica| Primary   | 8762 | 9181 | 8819 | 9036 | 41,64                  |
| 706 | Laznica   | Secondary | 9576 | 9943 | 9404 | 9560 | 38,44                  |
| 342 | Dogoše    | Secondary | na   | 11342| 10700| na   | 38,15                  |
| 488 | Celestrina| Tertiary  | 3525 | 3690 | 3417 | 3480 | 43,84                  |
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Precipitation and the weak associations between air pressure and temperature, temperature and wind direction and relative humidity and wind speed/direction. The NO₂ concentrations at the monitoring station in the centre of Maribor were weakly associated with air pressure and temperature and slightly associated with wind speed. On the other hand, the NO₂ concentrations at the Tezno monitoring station were moderately associated with wind speed and consequently weakly associated with relative humidity and wind direction. The NO₂ data from the two monitoring stations were moderately correlated, indicating that they had a common NO₂ source.

The results clearly prove the importance of wind transport of NO₂ to Tezno.

The linear correlations of hourly NO₂ and meteorological parameters are shown in Table 5. The italic text indicates a positive linear correlation (value above 0.1), the regular text no correlation (value around 0) and the bold text a negative correlation (value below -0.1). Some correlations between meteorological parameters were expected; the moderate association between temperature and precipitation and the weak associations between air pressure and temperature, temperature and wind direction and relative humidity and wind speed/direction. The NO₂ concentrations at the monitoring station in the centre of Maribor were weakly associated with air pressure and temperature and slightly associated with wind speed. On the other hand, the NO₂ concentrations at the Tezno monitoring station were moderately associated with wind speed and consequently weakly associated with relative humidity and wind direction. The NO₂ data from the two monitoring stations were moderately correlated, indicating that they had a common NO₂ source. The results clearly prove the importance of wind transport of NO₂ to Tezno.

The linear correlations of hourly NO₂ and traffic data are shown in Table 6. The NO₂ concentrations at the Maribor center monitoring station were moderately associated to the traffic volume of all counting stations, which confirms that road traffic is the main source of NO₂ in this area. The same applies to the correlations with the dominant passenger cars.
Table 5 – Correlations between hourly NO$_2$ and meteorological data

|                      | Air pressure | Temp. | Humidity | Precip. | Wind speed | Wind direct. | NO$_2$ MB center | NO$_2$ Tezno |
|----------------------|--------------|-------|----------|---------|------------|--------------|------------------|-------------|
| **Air pressure**     | ρ            | x     |          |         |            |              |                  |             |
|                      | p            |       |          |         |            |              |                  |             |
| **Temperature**      | ρ -0.301     | x     |          |         |            |              |                  |             |
|                      | p < 0.001    |       |          |         |            |              |                  |             |
| **Humidity**         | ρ -0.153     | -0.626|x         |         |            |              |                  |             |
|                      | p < 0.001    | < 0.001|          |         |            |              |                  |             |
| **Precipitation**    | ρ -0.114     | -0.028| 0.183    | x       |            |              |                  |             |
|                      | p < 0.001    | 0.279 | < 0.001  | x       |            |              |                  |             |
| **Wind speed**       | ρ -0.036     | 0.188 | -0.386   | 0.029   | x          |              |                  |             |
|                      | p 0.164      | < 0.001| < 0.001  | 0.263   | x          |              |                  |             |
| **Wind direction**   | ρ -0.041     | -0.195| 0.338    | 0.060   | -0.132     | x            |                  |             |
|                      | p 0.113      | < 0.001| < 0.001  | 0.022   | < 0.001    | x            |                  |             |
| **NO$_2$ MB center** | ρ -0.344     | 0.315 | -0.006   | -0.019  | -0.140     | -0.008       | x                |             |
|                      | p < 0.001    | < 0.001|          | 0.838   | 0.476      | < 0.001      | 0.774           |             |
| **NO$_2$ Tezno**     | ρ -0.041     | -0.030| 0.331    | -0.047  | -0.509     | 0.354        | 0.510           | x           |
|                      | p 0.005      | 0.319 | 0.422    | 0.345   | 0.376      | 0.662        | 0.089           |             |

Table 6 – Correlations between hourly NO$_2$ and traffic data

|                      | NO$_2$ Maribor center | NO$_2$ Tezno |
|----------------------|------------------------|--------------|
|                      | PC         | HGV         | All         | PC         | HGV         | All         |
| **Ptujska AC**       | ρ 0.542    | 0.475       | 0.527       | 0.144      | 0.119       | 0.147       |
|                      | p < 0.001  | < 0.001     | < 0.001     | 0.633      | 0.739       | < 0.001     |
| **Malečnik AC**      | ρ 0.566    | 0.466       | 0.544       | 0.180      | 0.122       | 0.151       |
|                      | p < 0.001  | < 0.001     | < 0.001     | 0.565      | 0.823       | < 0.001     |
| **Pobrežje HC**      | ρ 0.433    | 0.352       | 0.509       | 0.082      | 0.040       | 0.089       |
|                      | p < 0.001  | < 0.001     | < 0.001     | 0.907      | 0.067       |             |
| **Meljska HC**       | ρ 0.432    | 0.325       | 0.505       | 0.071      | 0.041       | 0.137       |
|                      | p < 0.001  | < 0.001     | < 0.001     | 0.864      | 0.077       | < 0.001     |
| **MB Ptujska**       | ρ 0.442    | 0.406       | 0.489       | 0.067      | 0.057       | 0.084       |
|                      | p < 0.001  | < 0.001     | < 0.001     | 0.859      | 0.137       |             |
| **Brestrnica**       | ρ 0.429    | 0.322       | 0.483       | 0.087      | 0.037       | 0.082       |
|                      | p < 0.001  | < 0.001     | < 0.001     | 0.563      | 0.198       |             |
| **Laznica**          | ρ 0.406    | 0.266       | 0.455       | 0.071      | -0.005      | 0.072       |
|                      | p < 0.001  | < 0.001     | < 0.001     | 0.968      | 0.026       |             |
| **Dogoše**           | ρ 0.395    | 0.139       | 0.438       | 0.161      | 0.073       | 0.079       |
|                      | p < 0.001  | < 0.001     | < 0.001     | 0.606      | 0.42        |             |
| **Celestrina**       | ρ 0.389    | 0.236       | 0.432       | 0.084      | 0.070       | 0.054       |
|                      | p < 0.001  | < 0.001     | < 0.001     | 0.529      | 0.017       |             |
consistent with that of Table 5, which indicates the important role of wind speed/direction for NO$_2$ concentrations in Tezno.

The moderate correlation between NO$_2$ data from the Tezno and Maribor center monitoring stations (Table 5) indicates their common sources. One of them is the city road traffic. The emitted NO$_2$ could be carried towards Tezno, which depends mainly on wind speed (Table 5). Consequently, the correlation between city traffic data and NO$_2$ concentration in Tezno is not significant. Nevertheless, some other NO$_2$ sources should not be overlooked in Tezno (e.g. heating system).

The variability of NO$_2$ concentrations per hour of the day at the Maribor center monitoring station is shown in Figure 5 for the historical period and the lockdown event. Two peak values of NO$_2$ concentrations can be seen. The highest occurs in the evening, the second in the morning rush hours (between 7 a.m. and 8 a.m.). In the early morning hours, NO$_2$ concentrations are low because their sources (e.g. traffic, heating systems) have low activity. The morning rise is the result of the reactivation of sources and is interrupted shortly after sunrise by the NO$_2$ inclusion in the O$_3$ formation. NO$_2$ concentrations are more or less constant during the day and start to rise in the evening due to active sources and the gradual termination of O$_3$ formation. After 8 p.m. NO$_2$ emissions decrease, and the remaining NO$_2$ is included in the O$_3$ decomposition. The shaded area represents the 95% confidence interval.

The differences between the NO$_2$ peak values of the historical period and the lockdown event were 13.1 μg/m$^3$ in the morning and 11.5 μg/m$^3$ in the evening (Figure 5). Compared to the historical
period, the morning peak was significantly stretched during the lockdown, which could be related to the lower emissions from traffic due to the smaller number of vehicles, the different fleet composition, less congestion and changed traffic flow regime.

4. CONCLUSIONS

The COVID-19 lockdown measures resulted in an average reduction of road traffic by 42% compared to the same periods in 2018 and 2019. The decrease in the daily number of passenger cars ranged from 56.4 to 60.3% on the motorway and from 33.9 to 44.6% on other road types. The decrease in heavy goods traffic was much smaller; 24.6% on the motorway, while for the other types of roads it changed from -3.2 to 16.1%.

The changes in traffic-related emissions due to the smaller number of vehicles, the different fleet composition, less congestion and the changed traffic flow regime during the lockdown period were reflected in the NO2 concentrations at least at the urban monitoring station, with road traffic being confirmed as the dominant source. Compared to the same periods in 2018 and 2019, the average NO2 concentration during the lockdown event decreased by 24 and 27%, respectively. The change is smaller than the change in traffic volume. The first explanation can be found in the increase of the NO2-dominant traffic sources; the emissions of diesel vehicles. As explained in the first paragraph of this section, the fleet composition was changed during the lockdown due to the increased load of heavy goods vehicles. Near the urban monitoring station, the daily decrease of passenger cars and heavy goods vehicles was 44% and 5.5%, respectively.

The second explanation can be found in the meteorological effects on NO2 dispersion. Considering that the meteorological conditions during the lockdown did not significantly deteriorate compared to the historic periods, the results show a significant correlation between the NO2 concentrations of the urban and urban background monitoring stations and prove the importance of wind transport of NO2 between them, e.g. firstly the wind speed and secondly the wind direction towards SE, parallel to the Drava River.

The presented results are relevant for the improvement of air quality management in small cities. They highlight the important role of reducing or replacing heavy goods traffic in urban logistics. However, the proposed mechanism and transformation pathways of NO2 should be subject to further studies focusing on the different meteorological conditions, seasonal and spatial variability and the relationship with other pollutants, in particular NOx, O3 and VOC.

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KAKO JE VPLIVAL OBSEG PROMETA NA KAKOVOST ZRAKA V MAJHNEM MESTU ZARADI EKSTREMNIH COVID-19 UKREPOV

IZVLEČEK

Ekstremni prometni ukrepi v obdobju COVID-19 so bili edinstvena priložnost za študij njihovega vpliva na koncentracije NO2 v Mariboru, ki se uvršča med mala slovenska mesta. Koncentracije NO2 prometni in meteorološki podatki so se statistično podrobnno obdelali za marec in april 2018, 2019 ter 2020, da bi dobili zgodovinski vpo- gled v njihove lastnosti in izluščili posebnosti obdobja COVID-19. Ta ekstremni dogodek je povzročil povprečno zmanjšanje cestnega prometa za 42%. Dnevno število osebnih avtomobilov se je znizalo za 33,9 do 60,3%, pri čemer je bil največji upad na avtocesti. Dnevno povprečje težkega tovornega prometa se je zmanjšalo na avtocesti za 24,6% in na hitri cesti za 7%. Na mesti opazovalni posta- jhi so se osredotočili predvsem na prometni in meteorološki podatki, z izjemo podatkov za enoto prvo gen. Podatki so se osredotočili na prometni in meteorološki podatki, z izjmo podatkov za enoto prvo gen. Predstavljeni rezultati so pomembni za oblikovanje urbanista in mobilnost v majhnih mestih. Poudarjamo pomembno vlogo reorganizacije težkega tovornega pro- meta v urbanisti.

KLJUČNE BESEDJE

cesti promet; ekstremni dogodek; COVID-19; NO2 izpusti; meteorološki pogoji; onesnaženje zraka.

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