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HOW THE VOLUME OF TRAFFIC AFFECTED AIR QUALITY DURING THE EXTREME EVENT OF COVID-19 LOCKDOWN IN A SMALL CITY

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 NO_2. Its concentrations were reduced by 25–60%; in Barcelona, Nice, 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 NO_2 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 NO_2 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 NO_2 concentrations at the urban monitoring station and the background monitoring station vary during the extreme event, and what was their reduction?
- How are the NO_2 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 NO_2 concentrations along a major arterial road and in the background?

The first aim of our study was to determine the effects of traffic on NO_2 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 NO_2 in Maribor and also the dispersion process of this pollutant in ambient air [1, 41]. Positive and negative correlations between meteorological variables and NO_2 were discussed based on studies in urban areas in Banja Luka, BIH [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 NO_2 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 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 sub-Pannonian characteristics [45]. The average annual air temperature ranges from 8 to 10 °C. The lowest monthly average temperature is recorded in January (-1.3°C) and the highest in July (19.7 °C). Precipitation has a typical continental regime with an average annual amount between 800 and 1050 mm. The climate in Maribor is characterised by sunny days; there are an average of 266 of them per year. Increased humidity and cloudiness occur in November and December, but fog is not characteristic of the city.

Maribor has an exceptional strategic geo-transport position and good transport connections to other settlements in Slovenia and to the neighbouring countries [46]. It is also located in the areas of the European Transport Corridors V and X. The Maribor motorway junction directs road traffic towards the Slovenian capital (Ljubljana), Austria, Hungary and Zagreb (Croatia). The railway junction directs railway traffic towards Ljubljana, Austria (Graz and Klagenfurt) and Hungary. Together with the airport, the city is defined as an intermodal land logistics centre, located about 220 km from the nearest Slovenian port in Koper. The Municipality of Maribor (MOM) has 19.6 km of motorways, 17 km of expressway, 35.5 km of primary roads, 14.7 secondary and 107.5 km of tertiary roads (*Figure 1*). Maribor is a regional centre, 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

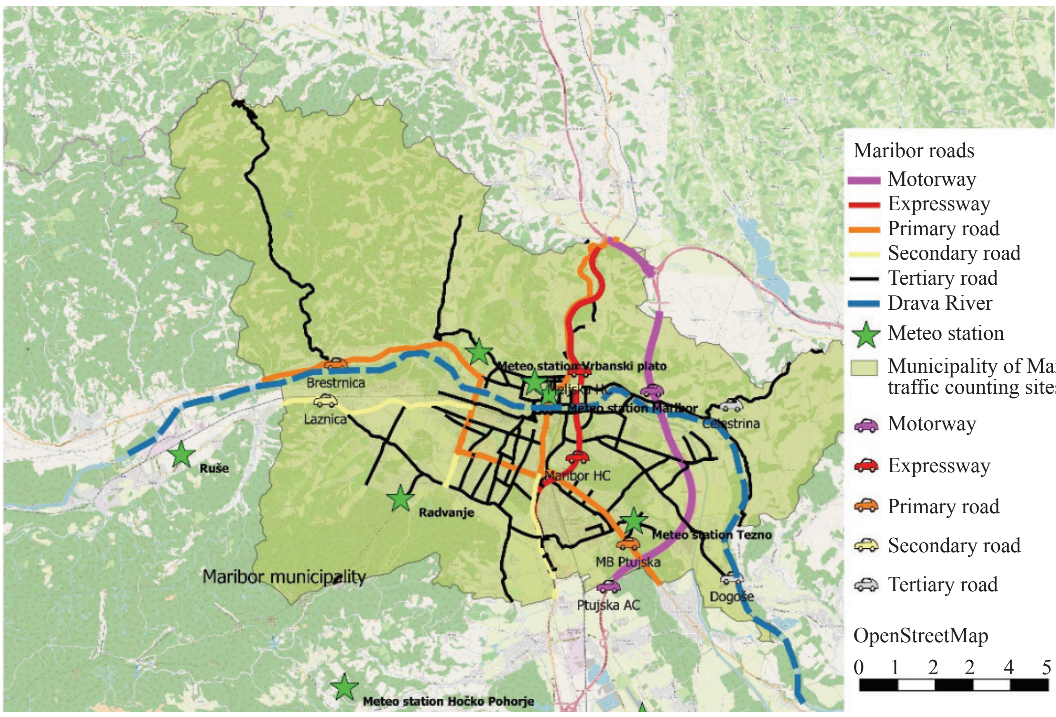


Figure 1 – Municipality of Maribor (MOM), road network and stations for air quality monitoring and traffic counting

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_x 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 Meljska HC), the primary road (MB Ptujska and Brestrnica) and the secondary road (Laznica, Dogoše) and one on the tertiary road (Celestrina; *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 Meljska 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 (ρ) 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

ρ 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 Meljska 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

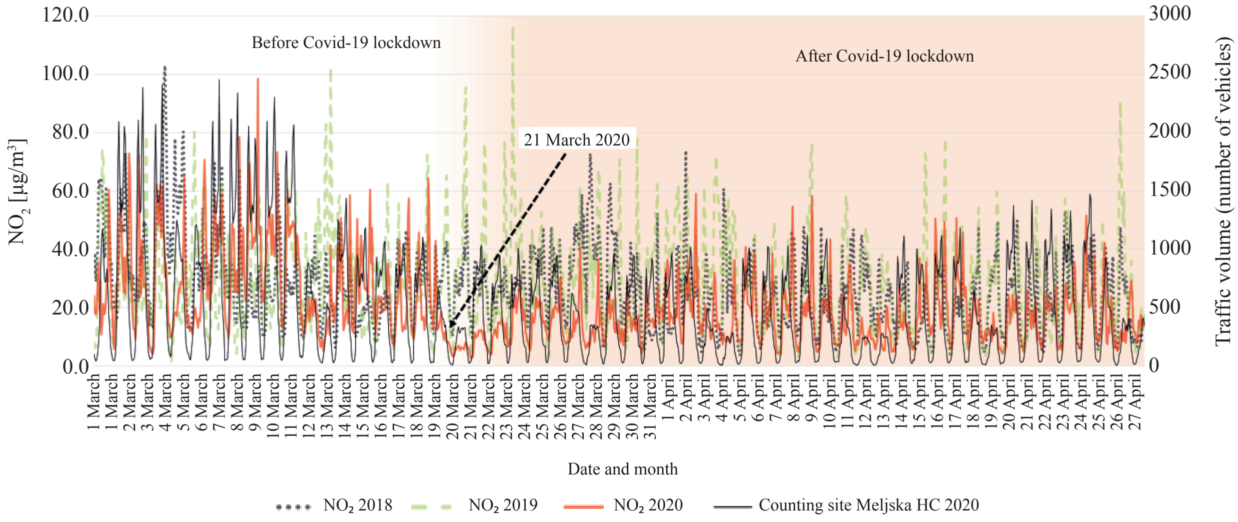


Figure 2 – Hourly NO_2 concentrations in the city of Maribor between March–April 2018 to 2020 and hourly traffic volume

lockdown event the average NO_2 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

	NO_2 [mg/m^3] Maribor Center	NO_2 [µg/m^3] Maribor Tezno	T [°C]	TV–PC MB Ptujska	TV–PC Meljska HC
Population	1205	1205	1205	1205	1205
Median	16.55	15.24	8.15	337.00	345.00
Mode	12.10	11.46	7.45	17.00	20.00
St. deviation	13.36	17.33	6.45	407.67	415.91
Minimum	2.70	0.00	-4.95	4.00	1.00
Maximum	98.50	111.00	25.05	2219.00	2223.00
Average	20.01	21.76	8.96	437.17	453.72

Table 3 – Weather and NO2 data during observed time period

	Air pressure [hPa]	Air temperature [°C]	Rel. humidity [%]	Precipitation [mm]	Wind speed [m/s]	NO_2^* [µg/m^3]
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

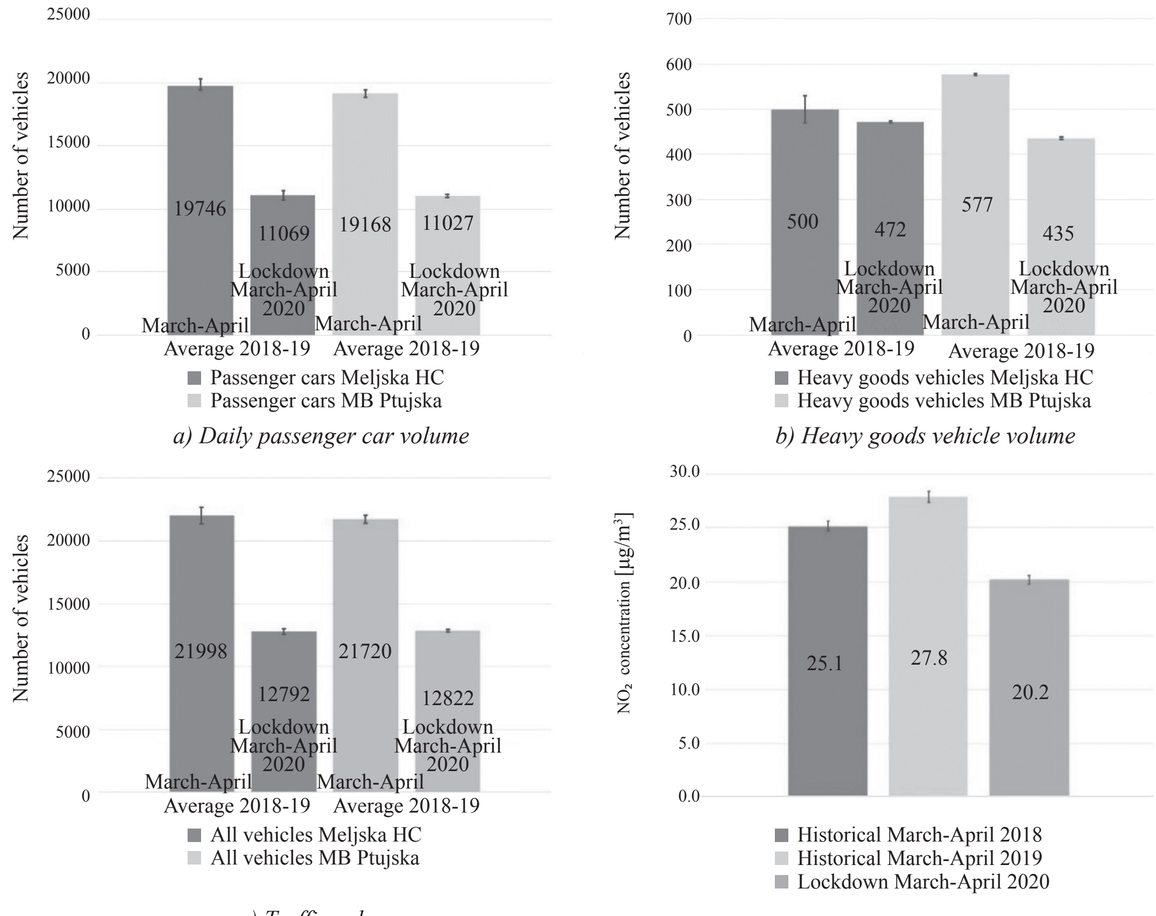
* *The parameter was analysed only for the Maribor center monitoring station, as the Tezno monitoring station has only been in operation since January 2020.*

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 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_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 – Average daily traffic volume data during observed time period

				Number of vehicles March-April		Number of vehicles March-April		Lockdown reduction (%)
	No.	TC name	Road type	2018	2019	2018	2019	
A) Passenger cars	840	Ptujska AC	Motorway	25668	27710	30864	31656	56,38
	889	Malečnik AC	Motorway	20393	21493	23327	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	na	10424	9945	10014	39,50
	488	Celestrina	Tertiary	3306	3440	3206	3249	44,65
B) Heavy goods vehicles	840	Ptujska AC	Motorway	7066	7.396	7.067	7119	24,41
	889	Malečnik AC	Motorway	6739	7.047	6.660	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	na	95	73	87	-3,16
	488	Celestrina	Tertiary	14	17	16	16	16,13
C) All vehicles	840	Ptujska AC	Motorway	37979	40618	43826	44769	49,53
	889	Malečnik AC	Motorway	31653	33330	37020	37530	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



a) Daily passenger car volume *b) Heavy goods vehicle volume*

c) Traffic volume *d) NO_2 concentrations in the urban station*

Figure 3 – Volume before and during the lockdown event (with standard error bars)

Ptujska), which are closest to the air quality monitoring stations. Compared to the period March–April 2018 and 2019, the average daily NO_2 concentration decreased by 24–27% in 2020 (*Figure 3d*). During the period discussed, the composition of the vehicle fleet at both traffic counting stations was similar (*Figures 3a–3c*). The main difference was the heavy goods vehicles volume (*Figure 3b*). During the lockdown event the volume of traffic at both counting stations decreased by 41%, mainly due to the decrease in passenger cars; 44% and 42% for Meljska HC and MB Ptujska counting stations, respectively (*Figures 3a and 3c*). Heavy goods transport decreased by only 5.5 and 24.6%, respectively.

The linear correlations of hourly NO_2 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 NO_2 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 NO_2 concentrations at the Tezno monitoring station were moderately associated with wind speed and consequently weakly associated with relative humidity and wind direction. The NO_2 data from the two monitoring stations were moderately correlated, indicating that they had a common NO_2 source. The results clearly prove the importance of wind transport of NO_2 to Tezno.

The linear correlations of hourly NO_2 and traffic data are shown in *Table 6*. The NO_2 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 NO_2 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	x							
Temperature	*ρ*	-0.301	x						
	p	< 0.001	x						
Humidity	*ρ*	-0.153	-0.626	x					
	p	< 0.001	< 0.001	x					
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	x	
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	x

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	

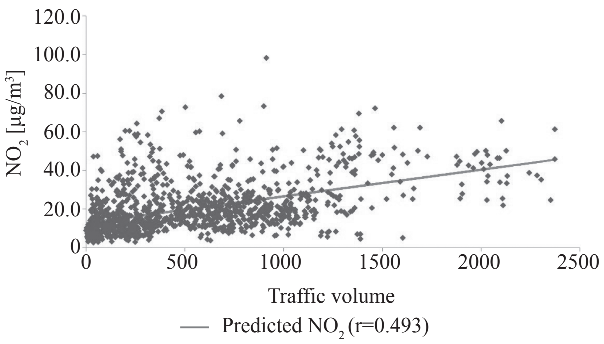


Figure 4 – Correlation between hourly NO_2 concentrations at the Maribor center monitoring station and the volume of passenger cars at the Meljska HC counting station

(*Figure 3*). The association was weak only with traffic data measured on tertiary roads in the eastern part of MOM (*Figure 1*). The correlations with heavy goods traffic were mainly weak, except for data measured on the motorway, followed by a primary road where the correlation was moderate. *Figure 4* illustrates the dependence of NO_2 concentration on the traffic volume in the nearby expressway (Meljska HC). The correlation in this specific example was positive and significant (ρ= 0.505) during the study period.

The situation is completely different for the Tezno monitoring station (*Table 6*), where are the data for passenger cars (PC), heavy goods vehicles (HGV) and all vehicles (all). The NO_2 concentrations were only weakly correlated with the traffic data from the motorway about 1000 m away in the direction of SE. The weak association was also observed with passenger cars on the nearest secondary road also in the direction of SE (Dogoše; *Figure 1*). This indicates the direction of NO_2 transport from the local road traffic parallel to the Drava River. The result is 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

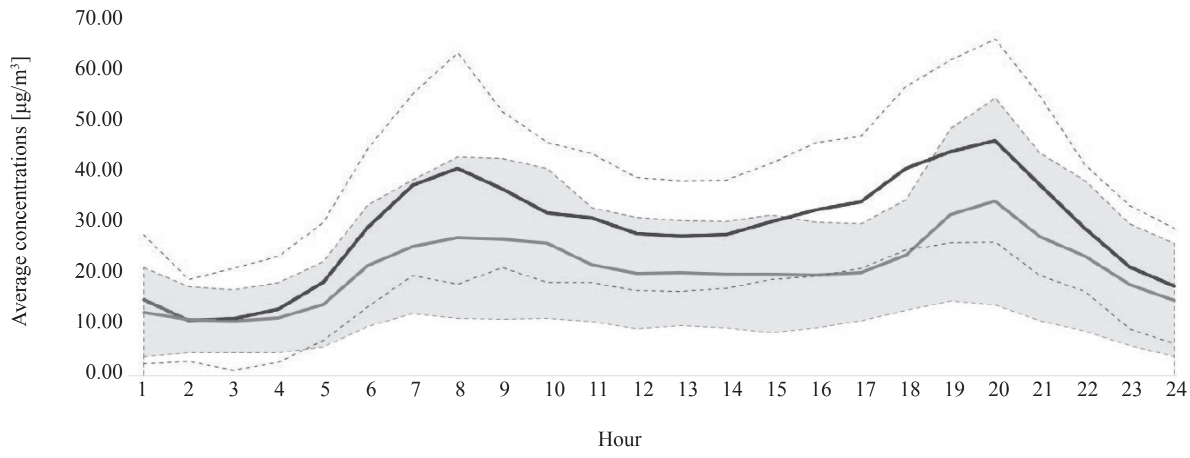


Figure 5 – Hour-of-day NO_2 concentration at the Maribor center monitoring station

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 NO_2 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 NO_2 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 NO_2-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 NO_2 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 NO_2 concentrations of the urban and urban background monitoring stations and prove the importance of wind transport of NO_2 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 NO_2 should be subject to further studies focusing on the different meteorological conditions, seasonal and spatial variability and the relationship with other pollutants, in particular NO_x, O_3 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 NO_2 v Mariboru, ki se uvršča med mala slovenska mesta. Koncentracije NO_2, prometni in meteorološki podatki so se statistično podrobno obdelani za marec in april 2018, 2019 ter 2020, da bi dobili zgodovinski vpogled 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 znižalo 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 mestni opazovalni postaji so se odsevale prometne značilnosti v 24-27% znižanju koncentracij NO_2. Znižanje je manjše od znižanja obsega prometa, kar bi lahko razložili s spremembo sestave voznega parka z večjim deležem vozil z višjimi izpusti NO_2, t. j. težkimi tovornimi vozili na dizelski pogon. Predstavljeni rezultati so pomembni za izboljšanje upravljanja s kakovostjo zraka in mobilnostjo v majhnih mestih. Poudarjajo pomembno vlogo reorganizacije težkega tovornega prometa v urbani logistiki.

KLJUČNE BESEDE

cestni promet; ekstremni dogodek; COVID-19; NO_2 izpusti; meteorološki pogoji; onesnaženje zraka.

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