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Original Research

Effects of the COVID-19 Quarantine Measures on $PM_{2.5}$, PM_{10} and NO_2 Concentration Levels in Serbia

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Abstract

The first case of COVID-19 infection in Serbia was confirmed in early March 2020. State of Emergency was declared soon afterward, imposing shelter in place measures and curfew in the evening hours. A number of countries around the world have experienced air quality improvements during the pandemic, caused by the mandatory quarantine. This study aims to analyze the effect of the quarantine on the air quality, by comparing $PM_{2.5}$, PM_{10}, and NO_2 concentration levels during 32 days quarantine period in the six cities in Serbia, from March 16 to April 16, 2020, with values obtained in the same period in 2019. NO_2 concentration levels showed significant reductions in all cities (36-71%). However, $PM_{2.5}$ and PM_{10} concentration levels did not show significant reductions in all cities. Concentration levels of $PM_{2.5}$ and PM_{10} were lower during the quarantine period only in two cities, by 2 and 19%, and 10 and 30% respectively. Analyzed values can assist decision-makers in defining the levels of effort and scope of actions that need to be undertaken in order to prevent the occurrence of high levels of concentration of PM2.5 and PM10 and to ensure clean and healthy air in Serbia.

Keywords: COVID-19, quarantine, $PM_{2.5}$, PM_{10}, nitrogen dioxide (NO_2)

Introduction

Air pollution represents one of the major environmental problem that has a direct association with the incidence of respiratory symptoms and decreased in pulmonary function [1]. However, COVID-19 lockdown has abruptly halted human activity, leading to a significant reduction in pollutant levels [2]. In the first quarter of 2020, the world is witnessing impressive sanitary, economic and environmental consequences caused by the COVID-19 pandemic. One of the consequences is the enforcement of lockdown and quarantine measures in many countries all over the world [3]. Transportation restriction, as one of the exceptional lockdown measures, had the effect of making the streets empty, practically without any vehicles [4]. One of the obligations during the lockdown was to stay at home in order to prevent the spread of

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the virus, which has had huge and expected impact on modification of anthropogenic emissions. In the infinity of negative consequences caused by the COVID-19 pandemic, there were some positive as well, as the answer to the question: What would happen with the air quality if public and intercity transportation stopped, thus eliminating almost all combustion vehicles from the cities?

In the late December 2019, China sent the alert to the World Health Organization (WHO), about various cases of unusual pneumonia which has started in city of Wuhan. During the first week of January 2020, the identification of a new virus, Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) named COVID-19 [5] was announced. At the demand of Chinese government, on January 23, entire country has been placed in the quarantine, as a measure to prevent the spread of infection and lessen the burden on health facilities [6]. With more than 118,000 cases of COVID-19 infection in more than 114 countries, on March 12, 2020, WHO announced COVID-19 outbreak as a pandemic [7].

First cases of COVID-19 infection in Europe were reported on February 21, 2020 [8]. Until April 2, 1 million cases and more than 52,000 deaths were reported with total number of 204 affected countries around the world, and two weeks later the number of cases had risen to more than 2 million [9]. As the cases spread, most of the countries adopted restrictions to the transportation, commerce and cultural activities, schools and universities were closed and exams were canceled, and social distancing measures were imposed [10].

In Serbia, the first case of COVID-19 infection was confirmed on March 6, 2020, in the city of Subotica, and until March 15, 47 confirmed cases of COVID-19 infection had been registered. On March 16, a State of Emergency was declared in order to prevent the spread of COVID-19 infection. This decision directly resulted in the lockdown of borders for foreign nationals, closure of pre-schools, elementary schools and high schools, higher education institutions, fitness centers and public parks. After only three days, a curfew had been imposed from 8 pm-5 am for everyone, while older than 65 were completely barred from leaving their homes at any part of the day. On March 19, International airport Nikola Tesla was closed, except for humanitarian and cargo flights, and on March 20 the first death case caused by COVID-19 was reported.

On March 21, complete quarantine was ordered: all borders for all passengers were closed, road, rail and river traffic were shut down, public urban and intercity transport were stopped, cafes and restaurants were closed, and all events were canceled.

Worldwide, lockdown measures have resulted in improved air quality in urban areas, with reports of exceptionally blue skies and very good visibility [4]. In many parts of the world, significant changes in air quality were observed in the period before and during the COVID-19 pandemic. Decrease in Nitrogen dioxide levels (NO_2) over China during quarantine compared to period before quarantine were identified [11]. Reduction of PM, CO and NO_2 levels in Brazil, Marocco and Kazakhstan were also reported [10, 12, 13]. The COVID-19 pandemic has negative social and economic effects, and on the other hand positive effects in the form of clean air and pollution-free environment across countries are visible [14]. Improvement in air quality due to the consequences caused by the COVID-19 pandemic does not represent any surprise. However, the impact and share of traffic and its high restrictions in cities, can allow us to know the scope of measures that should be applied for improving air quality in urban areas [4].

Many studies have shown that the long exposure to air pollution, especially toxic components, such as PM and NO_2, can lead to a chain of destructive processes in the body that can end with hypertension [15], heart and cardiovascular diseases [16] poor lung function in adults [17] and diabetes [18]. Also, some emerging evidence suggests that exposure to higher concentrations of pollutants such as $PM_{2.5}$ and NO_2 can increase the risk of health complications for individuals infected with COVID-19 [19, 20]. Increased air pollution and higher concentration of $PM_{2.5}$ can cause progressive inflammation of the respiratory pathways producing more mucous and less ciliary movement which results in acute respiratory infections in people [21]. The WHO warns about the health issues arising from NO_2 and suggests that the world population should be protected from exposure to this pollutant [20].

The objective of this study is to assess and compare $PM_{2.5}$, PM_{10} and NO_2 hourly observations in the six cities in Serbia, obtained during the quarantine period caused by COVID-19 pandemic (March 16 to April 16) in 2020 with values obtained in the same period of 2019. This study aims to assess the impacts of COVID-19 quarantine measures (reduction of public transport, shut down of schools and universities, closure of businesses and industries) on the air quality in Serbia, which is one of the most air polluted countries in Europe.

Material and Methods

Studied Area

The Republic of Serbia is a landlocked country located at the intersection of Central and Southeastern Europe in the southern Pannonia lowlands and the central Balkans, with about 6.9 million permanent residents according to the Republican Bureau of Statistics from 2018 [22]. The countries bordering on the west are the Republic of Bosnia and Herzegovina and the Slavonian region of the Republic of Croatia. Serbia joins Hungary in the north, Romania and Bulgaria in the east, northern Macedonia in the south, and Montenegro in the southwest. Kosovo, which Serbia

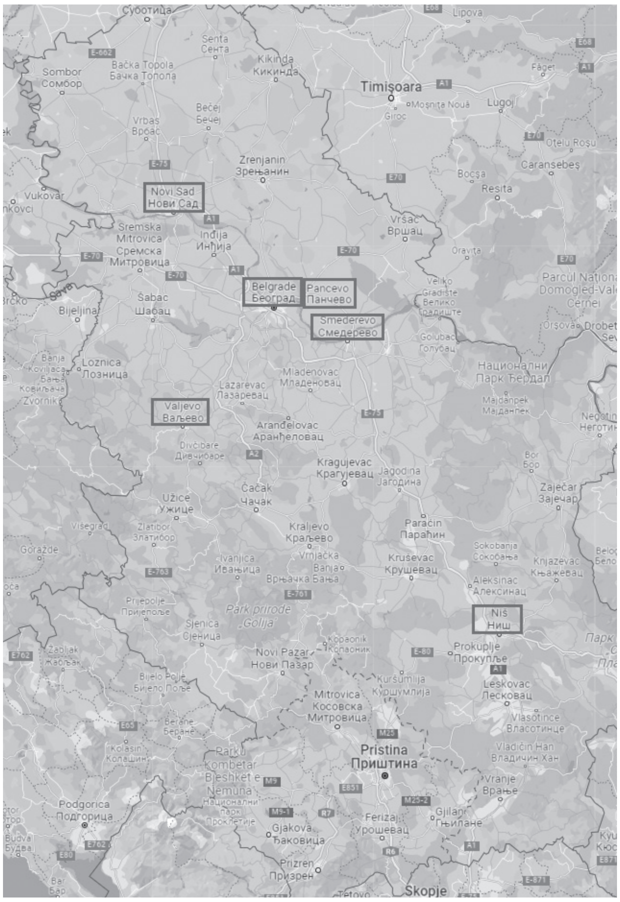

Fig. 1. Location of the investigated cities.

does not recognize as an independent country, also lies in the south, along the northeastern border of Albania.

In this study, six Serbian cities, shown in Fig. 1 and Table 1 with the available concentration values for $PM_{2.5}$, PM_{10} and NO_2 in 2019 and 2020, for period March 16-April 16, were analyzed.

Experimental Data

Two sets of air quality data for two periods have been used in this study. The first set includes the period from March 16 to April 16, 2019, and the second set, period from March 16 to April 16, 2020 (period during the state of emergency caused by COVID-19 pandemic).

Data from all six air quality monitoring stations in Serbia, made available by Serbian Environmental Protection Agency (SEPA) and Serbian National Air Monitoring network, were used to assess the levels of $PM_{2.5}$, PM_{10} and NO_2. For each station, available hourly and daily data for two periods were used to calculate the mean levels of each pollutant for each day and analyzed period, before and during quarantine. Furthermore, the variations in mean concentrations for mentioned pollutants were calculated to assess relative change (%) comparing the periods before and during quarantine.

Following the Law on Air Protection, the Serbian Environmental Protection Agency (SEPA) has the authority over the state network for air quality monitoring at the level of the Republic of Serbia [23]. Operational monitoring, using automatic reference methods, is carried out per the decree on determining the air quality control program in the state network and the decree on conditions for monitoring and air quality requirements [24, 25]. Fulfilling the obligations of informing the public about air quality, the Environmental Protection Agency presents the results of automatic air quality monitoring in real-time. The SEPA on its website in real-time gives a unified presentation of data from automatic air quality monitoring in the Republic of Serbia [26]. The display contains data from the national and local networks of measuring stations. The analyzers used to measure gases of NO_2 concentration levels are of the Teledyne T200 API type. The Grimm Model 180 particle size analyzer/dust monitor determines PM concentrations.

Model Teledyne T200 NO/NO_2/NO_x analyzer uses the chemiluminescence detection principle, coupled with state-of-the-art electronics to allow accurate and dependable low-level measurements for use as an ambient air analyzer. The quality control (QC) procedure consists of both automatic quality control checks and manually initiated QC checks conducted during site visits at required routine intervals.

The particle size analyzer/dust-monitor Grimm Model 180 uses the continuous measurement of PM in the air. The ambient air, to be analyzed, is drawn into the unit via an internal volume-controlled pump at a rate of 1.2 L/min. The sample passes through the measuring cell, past the laser diode detector,

Table 1. Main characteristics of monitoring locations with measured air quality data provided.

City	Classification	Zone	Pollutant	Latitude	Longitude	Altitude (m)
Novi Sad	Traffic	Urban	$PM_{2.5}$, PM_{10}, NO_2	45° 15' 45'' N	19° 49' 8'' E	78
Pančevo	Industrial	Suburban	$PM_{2.5}$, PM_{10}, NO_2	44° 51' 31'' N	20° 38' 56'' E	80
Belgrade	Background	Urban	$PM_{2.5}$, PM_{10}, NO_2	44° 48' 11'' N	20° 24' 0'' E	74
Valjevo	Background	Urban	$PM_{2.5}$, PM_{10}, NO_2	44° 16' 22'' N	19° 53' 56'' E	181
Smederevo	Traffic	Urban	$PM_{2.5}$, PM_{10}, NO_2	44° 39' 50'' N	20° 55' 36'' E	79
Niš	Traffic	Urban	$PM_{2.5}$, PM_{10}, NO_2	43° 19' 28'' N	21° 54' 11'' E	200

and is collected onto a filter. The pump also generates the necessary clean sheath air, filtered and passed through the sheath air regulator back into the optical chamber. This ensures that no dust contamination comes in contact with the laser-optic assembly. This particle-free airflow is also used for the reference-zero tests during the auto-calibration reported in various modes.

Statistical Analysis

The monitoring results were subjected to statistical analysis. The analysis of results was performed with IBM SPSS v21 (IBM SPSS Statistics forWindows, Version 21.0. Armonk, NY, USA: IBM Corp.). The Paired Samples T-test was used to assess the effect of quarantine on the concentration levels of three categories of pollutants: suspended particles from the PM_{10} and $PM_{2.5}$ and NO_2 categories. During the calculation, hourly values at all 6 locations were taken into account to determine the level of significance of the impact of quarantine on lowering the concentration levels of selected pollutants in the territory of the Republic of Serbia. The magnitude of the impact of quarantine on the relevant categories was estimated using indicator η^2, which can have values from 0 to 1. Guidelines for interpreting this indicator are as follows: 0.01-0.06- small impact, 0.06-0.14- moderate impact, a value above 0.14 indicates a large impact.

Results and Discussion

Air quality levels for $PM_{2.5}$, PM_{10} and NO_2 in Serbia, provided by SEPA, were obtained for 32 days of quarantine period, from March 16 to April 16, 2020, at the monitoring stations in cities of Novi Sad, Pančevo, Belgrade, Smederevo, Valjevo and Niš. During analyzed period, a State of Emergency was in force in Serbia, borders were closed, universities and restaurants were closed, public and intercity transport was shut down, and a ban on movement was imposed in certain parts of the day, and occasionally for several days in a row.

Results of the T-test

The effect of quarantine on the concentration levels of three categories of pollutants was assessed by the paired samples T-test. Suspended particles from categories PM_{10} and $PM_{2.5}$, and NO_2. There was a statistically significant decrease in the concentration levels of suspended particles from the PM_{10} category in the quarantine period (M = 39.19, SD = 27.38) compared to the pre-quarantine period (M = 40.54, SD = 26.54), t (4133) = 2.46, $p<0.05$. The mean decrease in value was 1.35, while 95% was CI (0.28, 2.42). The coefficient η^2, which expresses the magnitude of the impact of quarantine, had a value of 0.0015, which indicates a small impact of quarantine on lowering the concentration levels of suspended particles from the PM_{10} category (Table 2).

When it comes to suspended particles from the $PM_{2.5}$ category, the result of the paired test did not show a statistically significant change in concentrations due to the impact of quarantine (Table 3) when we compare the results from 2019 and 2020.

When we talk about the impact of quarantine on the concentration levels of monitored pollutants, we can say that the strongest impact of quarantine and reductions in traffic intensity has on NO_2 concentration levels. Namely, the T-test results of paired samples showed a drastic reduction in NO_2 concentration levels in the Republic of Serbia territory due to the reduction of traffic during the quarantine period. The mentioned decrease in concentration levels in 2019 (M = 37.61, SD = 43.40) compared to the measurement results from 2020 (M = 15.95, SD = 14.93) is statistically significant t (4454) = 31.71, $p <0.0005$. The average decrease in concentration levels was 21.65, while 95% was CI (20.31, 22.99). The value of $\eta^2 = 0.18$ indicates that the effect of quarantine on lowering the concentrations of this pollutant is extremely large (Table 3).

Impact of the COVID-19 Quarantine on the Concentration Values of $PM_{2.5}$

Serbia implemented strict traffic restrictions of movement during quarantine period to control the expansion of COVID-19. At the beginning, the assumption was that during 32-days period, these

Table 2. Paired Samples Statistics.

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PM_{10} (2019)	40.5395	4134	26.53553	.41271
	PM_{10} (2020)	39.1906	4134	27.38489	.42592
Pair 2	$PM_{2.5}$ (2019)	27.8579	4105	18.93909	.29560
	$PM_{2.5}$ (2020)	28.7065	4105	22.48713	.35098
Pair 3	NO_2 (2019)	37.6050	4455	43.39853	.65021
	NO_2 (2020)	15.9526	4455	14.23866	.21333

Table 3. The results of paired samples T- test.

		Paired Differences					t	df	Sig. (2-tailed)	η^2
		Mean	Std. Dev	Std. Error Mean	95% Confidence Interval of the Difference					
					Lower	Upper				
Pair 1	PM_{10} (2019) PM_{10} (2020)	1.35	35.21	.55	.28	2.42	2.46	4133	.014	0.0015
Pair 2	$PM_{2.5}$ (2019) $PM_{2.5}$ (2020)	.85	27.89	.44	-1.70	.005	-1.95	4104	.051	-
Pair 3	NO_2 (2019) NO_2 (2020)	21.65	45.57	.68	20.31	22.99	31.71	4454	.000	0.18

actions will generate changes in air pollution, especially in concentration of PM2.5. However, concentration levels of PM2.5 were not reduced throughout the entire country during the quarantine period caused by COVID-19 pandemic, shown in Table 4.

The average 32-days concentration levels of $PM_{2.5}$ have small variations across the stations during the quarantine, from 29 to 36 μg m^{-3} and during the same period in 2019, those variations are slightly higher and between 24 and 38 μg m^{-3}. The average values of $PM_{2.5}$ concentration during the quarantine period indicate a 10% reduction in 2020 compared to the same period in 2019, only in one city – Valjevo.

In all other analyzed cities, concentration levels of $PM_{2.5}$ were higher during quarantine period, from 12% to 41%, compared to the same period in 2019 (Fig. 2).

Higher concentrations of $PM_{2.5}$ are recorded in all analyzed cities during quarantine period in 2020, in comparison to the same period the year before. One of the reasons that must be taken into consideration is atypical transport of huge amounts of sand from thousands of kilometers from the east as a result of the meteorological synoptic situation in Central Europe, which caused the sudden increase of $PM_{2.5}$ particles at the end of the second week (March 27-30) of the quarantine in entire Serbia in all six analyzed stations and cities (Fig. 3).

If the period from March 27-30 (3-day values) was omitted from the calculation, when mentioned phenomenon occurred, the obtained results would remain similar to the previous and show the decrease in the levels of $PM_{2.5}$ particles in 2 analyzed stations and cities. On 4 analyzed stations the average levels of $PM_{2.5}$ remained in higher levels than in the same period in 2019 (Table 5).

Although significant changes and reductions in the concentration levels of $PM_{2.5}$ particles have been recorded worldwide, data from Serbia, from 6 measuring stations and cities, show a different picture. Despite the state of quarantine, closure of schools, universities, restaurants and shutdown of public transport, in urban areas air quality from the aspect of concentration levels of $PM_{2.5}$ particles was not improving, as originally expected.

Impact of the COVID19 Quarantine on the Concentration Values of PM_{10}

Similar to previous section and analysis of the impact of quarantine measurement on air quality and concentration levels of $PM_{2.5}$, concentration levels of PM_{10} were also not reduced throughout the entire country during the quarantine period, shown in Table 6.

The average 32-days concentration levels of PM_{10} have small variations across the stations during

Table 4. Average values of $PM_{2.5}$ concentration levels (μg m^{-3}) in the period between March 16 and April 16, in 2019 and 2020.

City	Period 16.03-16.04								%
	2019				2020				
	Average	Max	Min	Median	Average	Max	Min	Median	
Novi Sad	24	190	4	20	29	181	5	20	+24
Pančevo	24	155	4	20	30	243	1	21	+28
Belgrade	28	82	5	24	31	163	4	23	+12
Smederevo	26	264	2	20	36	204	4	27	+41
Valjevo	38	160	4	32	34	182	2	25	-10
Niš	28	110	4	24	35	156	5	26	+23

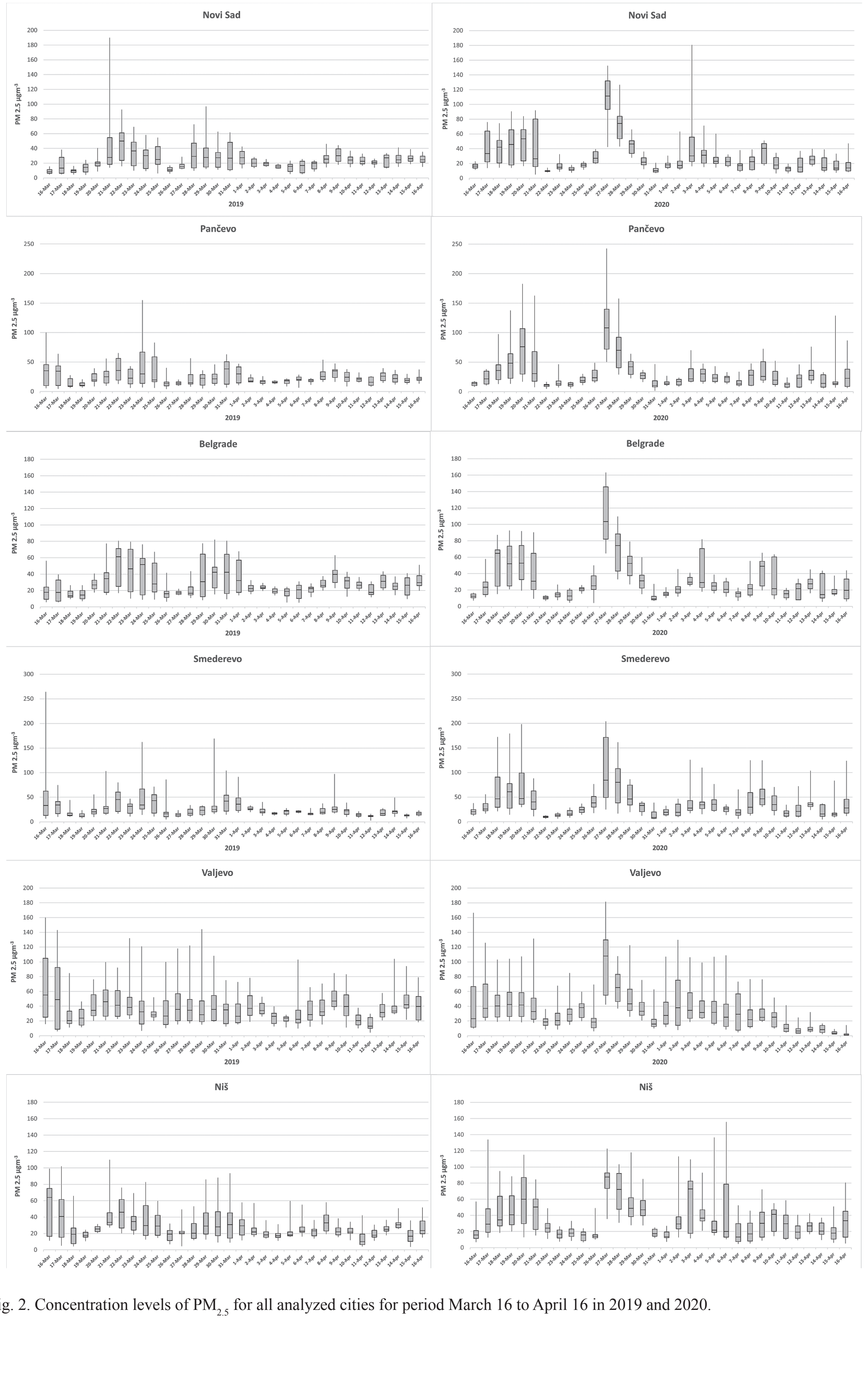

Fig. 2. Concentration levels of $PM_{2.5}$ for all analyzed cities for period March 16 to April 16 in 2019 and 2020.

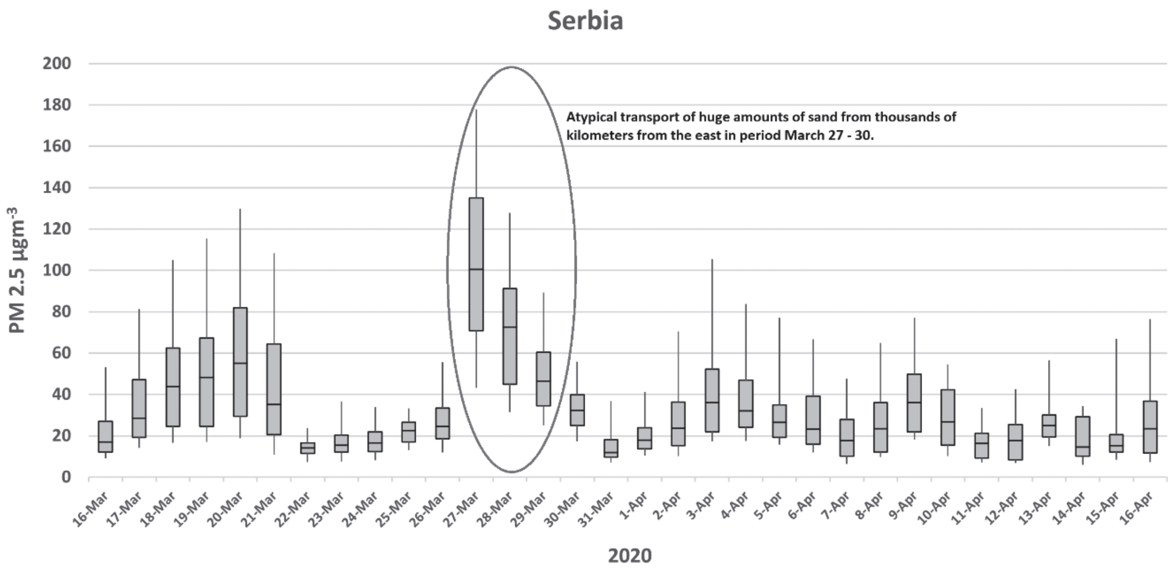

Fig. 3. Concentration levels of $PM_{2.5}$ in Serbia, in 2020 quarantine period, from six analyzed stations, with an emphasis on the phenomenon during March 27-30.

the quarantine, from 43 to 60 µg m^{-3} and during the same period in 2019 those variations are similar and between 34 and 51 µg m^{-3}. The average values of PM_{10} concentration during the quarantine period indicate a reduction of the 13% in 2020 compared to the same period in 2019, only in one city – Valjevo.

Table 5. Average values of $PM_{2.5}$ concentration levels (µg m^{-3}) in the period between March 16 and April 16, in 2019 and 2020 without sand transport phenomena.

City	Period 16.03-16.04								%
	2019				2020				
	Average	Max	Min	Median	Average	Max	Min	Median	
Novi Sad	24	190	4	20	25	181	5	19	+4
Pančevo	24	155	4	20	26	183	1	19	+8
Belgrade	28	82	5	24	26	92	4	22	-5
Smederevo	26	264	2	20	32	198	4	26	+25
Valjevo	38	160	4	32	3	167	1	25	-15
Niš	28	110	4	24	32	156	5	24	+11

Table 6. Average values of PM_{10} concentration levels (µg m^{-3}) in the period between March 16 and April 16, in 2019 and 2020.

City	Period 16.03 – 16.04								%
	2019				2020				
	Average	Max	Min	Median	Average	Max	Min	Median	
Novi Sad	45	206	7	32	60	399	8	39	+33
Pančevo	39	208	5	32	43	318	5	29	+11
Belgrade	36	93	6	32	51	450	5	34	+42
Smederevo	41	301	2	33	52	303	3	41	+28
Valjevo	51	192	4	44	44	256	2	34	-13
Niš	34	117	6	3	45	206	7	32	+31

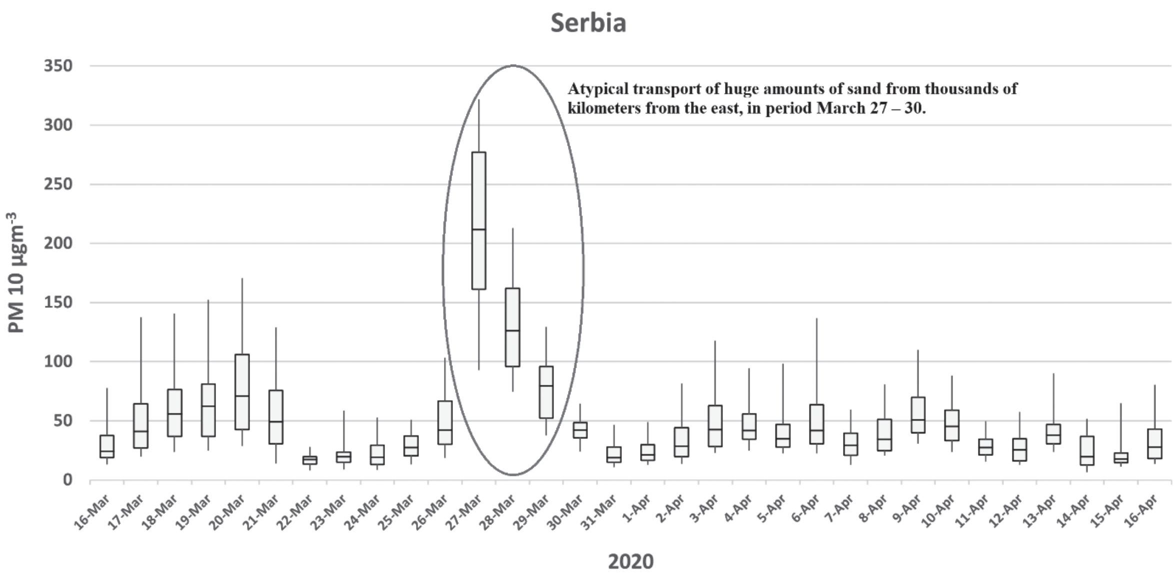

Fig. 4. Concentration levels of PM_{10} in Serbia, in 2020 quarantine period, from six analyzed stations, with an emphasis on the phenomenon during March 27-30.

In all other analyzed cities concentration levels of PM_{10} were higher during quarantine period, from 11% up to 42%, compared to the same period in 2019.

In this case, phenomenon of atypical transport of huge amounts of sand from thousands of kilometers from the east, in period from March 27-30, which influenced the appearance of high average and maximum values and concentration levels of PM_{10} particles at all 6 measurement stations in Serbia must be considered (Fig. 4).

If the period from March 27-30 (3-day values) was omitted from the calculation, when mentioned phenomenon occurred, the obtained results would remain almost similar to the previous and show the decrease in the levels of PM_{10} particles in 2 analyzed stations and cities (Fig. 5). On other 4 analyzed stations the average levels of PM_{10} still remained in higher levels than in the same period in 2019 (Table 7).

Although significant changes and reductions in the concentration levels of PM_{10} particles have been recorded worldwide, data from Serbia, from 6 measuring stations and cities, show a different picture. Despite the state of quarantine, closure of schools, universities, restaurants and shutdown of public transport, similarly to concentration levels of $PM_{2.5}$, in urban areas air quality from the aspect of concentration levels of PM_{10} particles did not show improvement in all cities, as originally expected. Two cities, Pančevo and Valjevo, recorded lower concentration levels of PM_{10} from 13% and 31% during quarantine, in comparison to the same period in 2019. Two biggest cities in Serbia, Belgrade and Novi Sad, recorded slight increase of concentration levels of PM_{10} from 4% and 2%, respectively, during quarantine. Two cities that recorded highest increase of concentration levels of PM_{10} from 11% were Smederevo and Niš.

Table 7. Average values of PM_{10} concentration levels (µg m^{-3}) in the period between March 16 and April 16, in 2019 and 2020 without sand transport phenomenon.

City	Period 16.03-16.04								%
	2019				2020				
	Average	Max	Min	Median	Average	Max	Min	Median	
Novi Sad	45	206	7	32	46	336	8	38	+2
Pančevo	39	208	5	32	34	195	5	28	-13
Belgrade	36	93	6	32	37	163	5	33	+4
Smederevo	41	301	2	33	45	276	3	38	+11
Valjevo	51	192	4	44	35	200	2	29	-31
Niš	34	117	6	3	38	181	7	31	+11

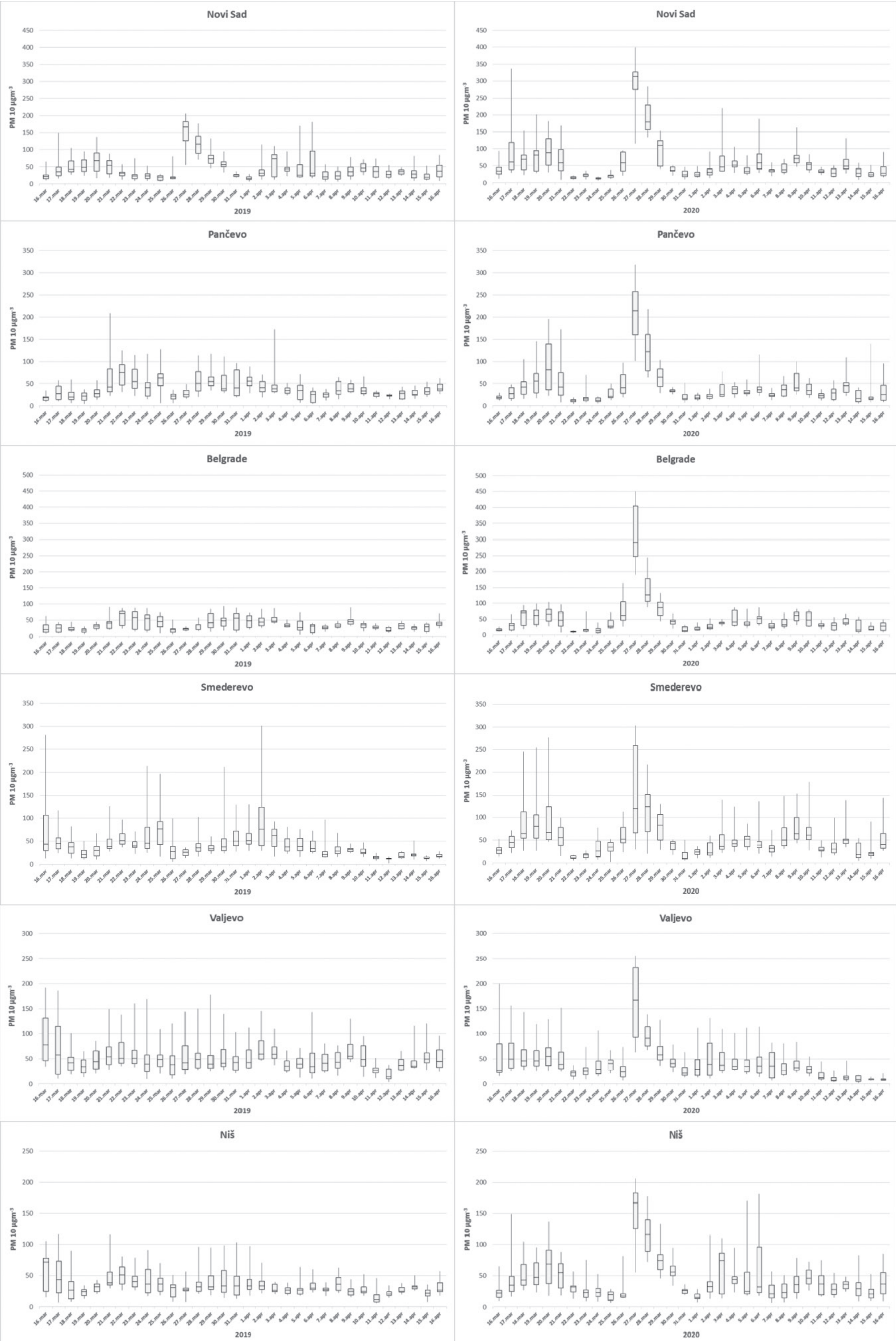

Fig. 5. Concentration levels of PM_{10} for 6 cities in Serbia during the period from March 16-April 16, in 2019 and 2020.

Table 8. Average values of NO_2 concentration levels (µg m^{-3}) in the period between March 16 and April 16, in 2019 and 2020.

City	Period 16.03 – 16.04								%
	2019				2020				
	Average	Max	Min	Median	Average	Max	Min	Median	
Novi Sad	64	431	1	34	19	107	1	12	-71
Pančevo	47	168	5	34	17	110	5	12	-64
Belgrade	28	123	4	21	10	139	1	6	-62
Smederevo	33	93	5	33	21	91	1	19	-37
Valjevo	27	87	3	24	15	81	1	12	-43
Niš	26	64	5	25	13	67	2	12	-49

Impact of the COVID19 Quarantine on the Concentration Values of NO_2

Serbia implemented strict traffic restrictions during quarantine period to control the spreading of COVID-19. In 32 days period, these actions generated changes in air pollution, especially in concentration of NO_2. Concentration levels of NO_2 were reduced throughout the entire country during the quarantine period caused by COVID-19 pandemic, shown in Table 8.

The average 32-days concentration levels of NO_2 have small variations across the stations during the quarantine, from 13 to 21 µg m^{-3} while during the same period in 2019 variations are higher and between 26 and 64 µg m^{-3}. The average values of NO_2 concentration during the quarantine period indicate a reduction of NO_2 concentration levels by 37%-71% in 2020, in all analyzed stations and cities, compared to the same period in 2019 (Fig. 6).

City of Novi Sad recorded the highest reductions of NO_2 by 71%, during a pandemic period in 2020 compared to 2019. In 2019, NO_2 concentration levels were between 1 and 431 µg m^{-3}, while in 2020 those levels were between 1 and 107 µg m^{-3}. During March 2019, 14 exceedances of the allowed daily average value of 40 µg m^{-3} were registered, while in the same period in 2020, 3 exceedances of the allowable value were registered.

City of Pančevo recorded the reduction of NO_2 concentration levels by 64% during the quarantine. In 2019, NO_2 concentration levels were between 5 and 168 µg m^{-3} with 14 days exceedance of EU limit value by average daily value, and the WHO annual reference value of 40 µg m^{-3}. In 2020 those levels were between 5 and 110 µg m^{-3}, and the average value was only one day exceeding the EU threshold.

City of Belgrade recorded the reduction of NO_2 concentration levels by 46% during the quarantine period. In 2019, NO_2 concentration levels were between 4 and 123 µg m^{-3}, with 2 days exceedance of WHO average daily value of 40 µg m^{-3}. In 2020, NO_2 concentration levels were between 1 and 139 µg m^{-3}, without exceeding WHO daily reference value.

City of Smederevo recorded the smallest reduction of NO_2 concentration levels by 37%. In 2019, NO_2 concentration levels were between 5 and 93 µg m^{-3}, with 6 days over 40 µg m^{-3}. Concentration values during the quarantine period in 2020 were between 1 and 91 µg m^{-3} and average daily value always lower than the EU limit value and the WHO annual reference value.

City of Valjevo recorded the reduction of NO_2 concentration levels by 43% during the quarantine period. In 2019, NO_2 concentration levels were between 3 and 87 µg m^{-3}, while in 2020 those levels were between 1 and 81 µg m^{-3}. In both analyzed periods, average daily values did not exceed the EU limit value and the WHO annual reference value of 40 µg m^{-3}.

City of Nis recorded the reduction of NO_2 concentration levels by 49% during period caused by COVID-19 pandemic. In 2019, NO_2 concentration levels were between 5 and 64 µg m^{-3}, with one exceedance of the average daily value. In 2020 those levels were between 2 and 67 µg m^{-3}, without exceeding the average daily value.

Conclusions

Quarantine measures and their impact, caused by COVID-19 pandemic, definitely led to improved environmental quality all over the world. The quarantine period was a unique opportunity for scientific community to confirm the thesis that the reduction of traffic emissions in cities will have huge impact on reduction of air pollution. Strict traffic restrictions in Serbia in combination with restriction of movement did have huge impact on NO_2 concentration levels which showed the significant reductions. All six analyzed cities in Serbia recorded the reduction of NO_2 concentration levels by 37 to 71%. The highest rate of reduction, 71%, is recorded in the second largest city in Serbia – City of Novi Sad. There was a unique opportunity for analysis on the scope of impact of urban and intercity transport on air quality in Serbia. The results showed that traffic-free conditions have huge impact on the reduction of NO_2 air pollution. A Number

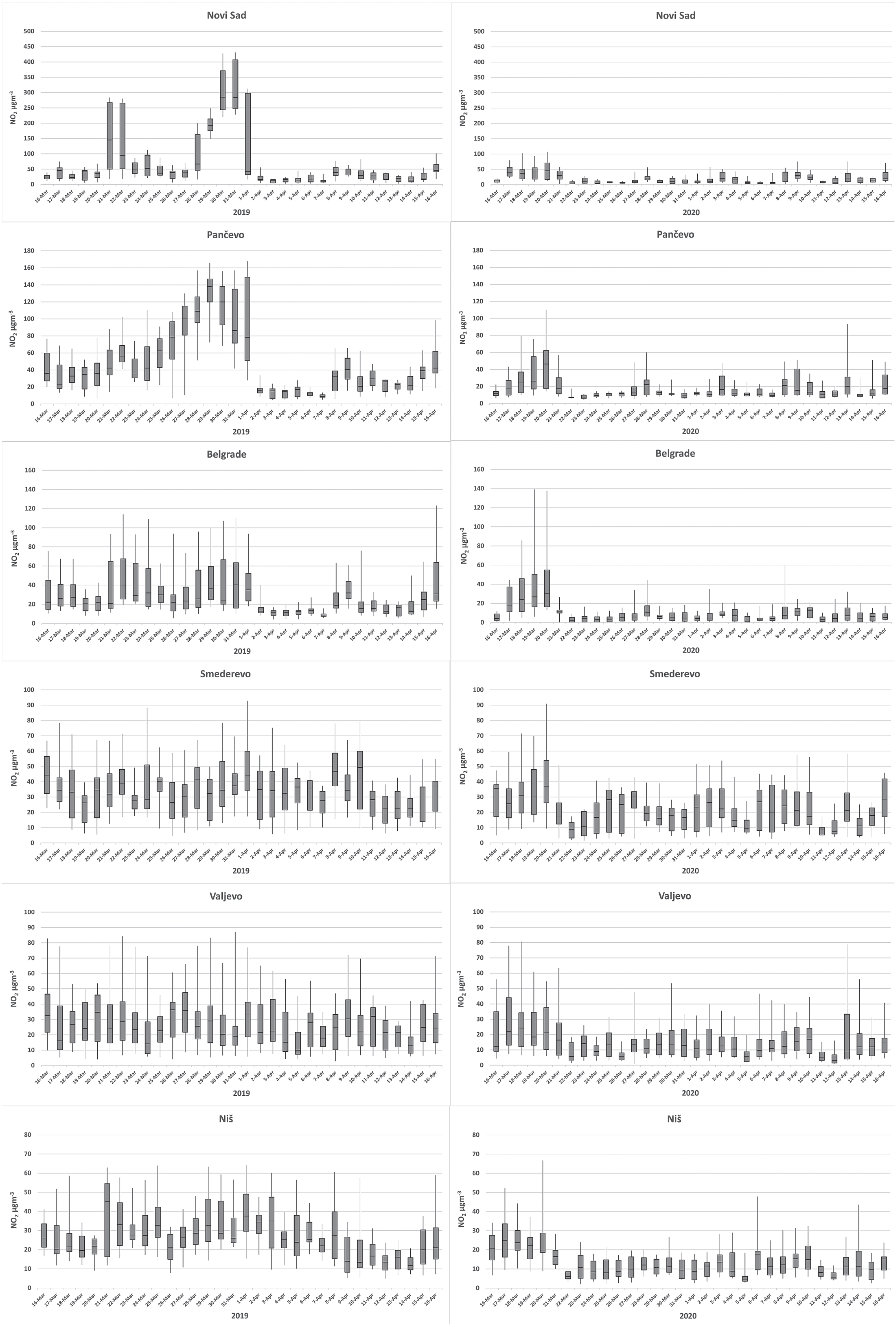

Fig. 6. Concentration levels of NO_2 for 6 cities in Serbia during the period from March 16-April 16, in 2019 and 2020.

of cities (Novi Sad, Pančevo, Belgrade and Smederevo) had average daily concentrations exceeding EU limit value and the WHO annual reference value of 40 μg m^{-3}, between 2 and 14 days, during analyzed period in 2019. In 2020 mentioned cities had no more than 3 days with average daily values higher than 40 μg m^{-3}.

Although there were a lot of negative consequences caused by the COVID19 pandemic in Serbia, some positive were recorded as well, such as lower concentration levels of NO_2 and slight improvement in air quality. However, other pollutants such as $PM_{2.5}$ and PM_{10} did not show positive changes in most of the cities with analyzed measurement stations in Serbia.

The impacts of COVID-19 quarantine measures, such as reduction of public transport, closure of schools, universities, businesses and industries, did not reflect positively from the aspect of improvement of air quality and reduction of concentration levels of $PM_{2.5}$. Only two cities out of six (Belgrade and Valjevo) recorded lower values of $PM_{2.5}$ concentration levels during quarantine, 5% and 15% respectively. Other cities recorded higher levels of $PM_{2.5}$ particles during quarantine, compared to the same period in 2019. Cities of Novi Sad and Pančevo had higher values from 4% and 8% respectively, and cities of Niš and Smederevo from 11% and 25%. It is important to note that these values were obtained after the exclusion of the phenomenon of atypical transport of huge amounts of sand from thousands of kilometers from the east, that occurred in the last week of March in 2020 (March 27-30) and during the second week of quarantine.

Resembling the case of $PM_{2.5}$ concentration levels, a similar fate, during quarantine, befell the levels of PM_{10} particles in Serbia. Cities of Pančevo and Valjevo recorded lower values of PM_{10} concentration levels, 13% and 31% respectively, during quarantine, compared to the same period in 2019. The other cities (Novi Sad, Belgrade, Niš and Smederevo) recorded higher values of PM_{10} particles in urban air, 2%, 4%, 11% and 11% respectively.

From all the above, it can be concluded that there is no unique picture that could describe the state of air quality in Serbia during quarantine caused by COVID-19 pandemic. Only concentration levels of NO_2 were lower in all analyzed cities, comparing the two periods. Concentration levels of $PM_{2.5}$ and PM_{10} were lower only in 3 cities, which clearly confirms that Serbia cannot be classified as a country that recorded an improvement in air quality during quarantine with all the measures that had been taken at that point.

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Conflict of Interest

The authors declare no conflict of interest.

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