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Air Quality Assessment During COVID-19: A Case Study of Serbia

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Abstract: The discovery of a new virus has forced many countries to introduce drastic measures at the beginning of the pandemic to protect human health. These measures include the reduced mobility of people and the reduction of certain economic activities. As a consequence, studies conducted in different countries have reported significant improvement in air quality. This paper aims to assess the impact of quarantine and lockdown measures on air quality in the city of Bor. Data regarding concentrations of PM_{10} and SO_2 were collected using three monitoring stations located in the urban part of the city and compared with corresponding periods in 2019 and 2021. The results have shown that concentrations of these pollutants were even higher during the lockdown period. Concentrations of SO_2 were 58 % higher compared to those in the corresponding period in 2019 and 56 % higher compared to those in 2021. The mean daily values of PM_{10} were 47 % higher compared to those in 2019 and 29 % higher compared to those in 2021.

Keywords: air pollution, lockdown, COVID-19.

INTRODUCTION

THE problem of air pollution, especially in urban areas, has existed for decades. Many efforts have been made to identify the main pollutants and reduce their emissions to improve people's quality of life. The discovery of the new SARS-COV-2 virus and the introduction of measures to prevent its spread have shed a whole new light on the existing problem and forced researchers to expand their field of research. Numerous studies have analysed air quality during the COVID-19 pandemic, focusing on the most relevant and representative pollutants such as PM, NOx, CO, O_3, and SO_2.[1–3] The results obtained in their research have provided an opportunity to assess the impact of anthropogenic activities in urban areas on the level of air pollution, identify the main sources of pollution, and make recommendations for cleaner air. The greatest improvement in air quality has been recorded in large cities, where traffic and industry are the main sources of pollution.[4] However, although the closure of cities has led to a significant reduction in pollution, the percentage of that reduction depends primarily on the type of city and the dominant source of pollution.[5–7]

The main sources of NO_2 in urban areas are transport, heating, and lighting.[8] Since the introduced measures reduced transport activities, the decrease in the concentration of this pollutant was the most evident.[9–11] However, a decrease in NO_2 concentration led to an increase in O_3 concentration.[7] Lower NO_2 concentrations are conditioned by NO concentrations, which results in reduced O_3 degradation.

PM_{10} and SO_2 are the most common pollutants in urban areas, and their impact on human health has been proven in many studies.[12–16] They occur most often as a result of anthropogenic activities such as transport and industry.[17,18] In many cities around the world, especially in China,[19] SO_2 concentrations have been brought to acceptable levels, so the decrease in concentrations of this pollutant during lockdown is the least evident or very imperceptible.[20] The reduction in PM_{10} concentration was also highlighted in European Environmental Agency (EEA) reports. However, it is difficult to assess the impact of the closure on PM_{10} concentrations given that several factors affect PM_{10} emissions. Interestingly, some studies have shown that the spread of particles is undoubtedly associated with the spread of the new virus, where PM appears both as a carrier and as a substrate for the SARS-COV-2 virus.[21,22] Although the obtained results confirmed that short-term or long-term exposure to polluted air might contribute to a higher possibility of virus infection,[23,24] the presence of pathogenic viruses in PM_{10} can be excluded given that viruses survive very shortly outside the living organism. On the other hand, air pollution can contribute to viral infections by reducing the defence mechanism of the host immune system and the airway macrophage response as well as boosting pro-inflammatory cytokines production.[25] Regardless of the position one takes, these facts unequivocally show that it is necessary to take measures to improve air quality as soon as possible and thus improve the quality of life and save the population's health.

When the first case of a coronavirus infection was detected, the Serbian authorities declared a state of emergency to prevent the spread of the pandemic and protect the health of the population, which meant the introduction of very strict measures. All cities in the country were closed, many commercial and industrial activities were restricted, restaurants, schools, and universities were closed, travel was restricted, and citizens were asked to stay in their homes and not to go out for no practical reason (going to work, going to the doctor). This situation lasted until 6 May 2020. Although such drastic measures have brought major economic problems[26,27] and led to social distancing,[28] they have brought some improvements, especially regarding air quality in large cities.[29,30] However, very few studies have been done regarding air quality during the lockdown in smaller areas, and therefore, this paper aims to evaluate air quality in Bor (Serbia) and analyse variations in air pollutants before, during, and after the largest closure in the recent history of the country. Bor is a small mining town in Eastern Serbia, known for exploiting and processing copper ores for more than 100 years. On the map of Europe, Bor is a black spot with registered high concentrations of SO_2 and PM_{10}.

EXPERIMENTAL

Study area

The city of Bor is located in the eastern part of the Republic of Serbia, covering 856 km^2. It lies 350–400 m above sea level, with the geographical coordinates 44°05'N and 22°06'E. It is a small mining and industrial city of 40,000 inhabitants (data from 2020) with developed non-ferrous extractive metallurgy. The copper smelter is located in the city's immediate vicinity, and the local population is

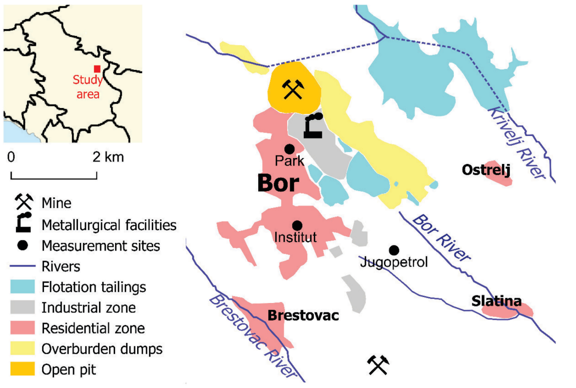

Figure 1. Locations of the measuring stations and the copper smelting plant in Bor (Serbia).

exposed to pollutants such as sulphur dioxide and PM_{10} with a high percentage of arsenic, lead, cadmium, mercury, and nickel.[31,32]

For this study, the daily concentrations of PM_{10} and SO_2 were collected at three measuring stations located in the vicinity of the smelting plant in Bor (Serbia) during a state of emergency with a lockdown (15 March–6 May 2020) in the Republic of Serbia as well as in the corresponding periods in 2019 and 2021. Two monitoring stations are urban-industrial, and one is suburban (Figure 1). The first monitoring station, the 'Institute', hereafter defined as IN, is located in the city area in the vicinity of the Mining and Metallurgy Institute Bor, about 2 km southeast of the copper smelting plant. The second station, the 'Town Park', hereafter defined as TP, is placed in the city park in the urban area and about 650 m west of the copper smelting plant. It is directly exposed to the effects of pollution. The third monitoring station, "Jugopetrol" (JP), is placed in the suburban and industrial area of the city, 2.5 km southeast of the smelting plant and 1 km northeast of the city landfill.

All publicly available data on air quality are provided by the Institute for Mining and Metallurgy in Bor, an accredited chemical laboratory. The sampling of SO_2 was conducted by the AT-801×-PE sampler and analysed by the titrimetric method SRPS ISO 4220:1997. The monitoring of SO_2 levels was performed daily during a calendar year. The sampling of PM_{10} was performed with the samplers of ambient air LVS3 Sven Leckel, MVS6 Sven Leckel, and LIFETEK PMS, MEGA SYSTEM SRL, and analysed by the gravimetric method SRPS EN 12341:2015. Whatman QM-A 47 mm quartz filters were used as the collection medium. Data availability for the defined periods was 100 % for SO_2 and less than 40 % for PM_{10} at some measuring points (PM_{10} was not measured at the JP measuring station in 2019).

The climate of the study area is moderate to medium continental, with a transition to a mild mountain in the higher mountain zones. During these three periods, data

Table 1. Daily average concentrations of SO_2 (μg m^{-3}) and PM_{10} (μg m^{-3}) during the state of emergency in 2020 and corresponding periods in 2019 and 2021; $p < 0.05$.

Air pollutant	Monitoring station	2019 (before)	2020 (lockdown)	2021 (after)	Differences before -lockdown (variation in %)	Differences after -lockdown (variation in %)
PM_{10}	TP	28	40	29	12 (30 %)	−11 (27 %)
	IN	26	49	35	23 (47 %)*	−14 (29 %)
	JP		56	41	/	−15 (27 %)*
SO_2	TP	61	114	50	53 (46 %)*	−64 (56 %)*
	IN	21	23	29	2 (9 %)	6 (21 %)
	JP	112	267	132	155 (58 %)*	−135 (51 %)*

regarding meteorological conditions (temperature, relative humidity, and atmospheric pressure) were obtained from the Mining and Metallurgy Institute in Bor website.

RESULTS AND DISCUSSION

The mean concentrations of the investigated pollutants during the studied periods as well as the differences among them are shown in Table 1.

During the three studied periods (2019, 2020, 2021), the mean daily concentrations of SO_2 were the highest in 2020 (267 μg m^{-3}) and the lowest in 2019 at measuring station IN (21 μg m^{-3}). Differences between these periods (2019 vs. 2020 and 2020 vs. 2021) were statistically significant ($p < 0.05$) except at measuring station IN.

The situation was the same regarding the daily average concentrations of PM_{10}. The mean values of this pollutant were the highest in 2020 (56 μg m^{-3}) and the lowest in 2019 (26 μg m^{-3}). The differences between the observed periods were statistically significant ($p < 0.05$) only between 2019 and 2020 for measuring station IN and between 2020 and 2021 for measuring station JP.

The impact of the meteorological conditions on air quality needs to be assessed since pollutant concentrations depend not only on emissions but also on weather conditions, transport, wet and dry depositions, and atmospheric chemistry. Table 2 presents the meteorological conditions over Serbia during the same time frame in 2019, 2020, and 2021.

The results have shown (Table 2) that the average daily values of temperature, wind speed, and relative humidity changed with statistical significance ($p < 0.05$). At the same time, the differences in atmospheric pressure were not statistically significant.

In addition, the evaluation of the Pearson correlation coefficients between PM_{10} and SO_2 concentration and meteorological factors such as temperature, humidity, air pressure, and wind speed (Table 3) has indicated that the correlation coefficients are all inversely correlated at three monitoring sites for all the three studied periods except for air pressure.

Based on Figure 2, it is evident that PM_{10} concentrations were the highest during the lockdown period compared to the corresponding periods in 2019 and 2021. During the observed period, the highest mean daily PM_{10} concentrations were recorded at the JP measuring point (253 μg m^{-3}) during the lockdown. It is important to emphasise that the PM_{10} concentrations exceeded the limit values (50 μg m^{-3}) several times during all the three observed periods but mostly during 2020 (Table 4).

Table 2. Statistical analysis of weather conditions during observed periods.

Meteorological parameters		M	SD	Min–Max	$p^{(a)}$
Temperature / °C					< 0.05
	2019	11.14	2.69	6.10–18.00	
	2020	9.71	5.50	−3.17–19.13	
	2021	8.18	4.97	1.14–21.97	
Relative humidity / %					< 0.05
	2019	65.36	16.85	39.30–99.00	
	2020	56.24	16.33	29.01–95.73	
	2021	68.55	15.28	43.06–99.92	
Atmospheric pressure / hPa					> 0.05
	2019	969.55	7.07	956.90–985.00	
	2020	971.50	6.37	960.59–986.40	
	2021	971.00	6.38	955.28–985.32	
Wind speed / m s^{-1}					< 0.05
	2019	1.35	0.75	0.5–3.9	
	2020	1.38	0.74	0.5–3.3	
	2021	2.11	0.92	0.8–5.5	

(a) values smaller than 0.05 are considered statistically significant

Table 3. Pearson correlation.

Measuring station	Year	Pollutant	Temperature / °C	Relative humidity / %	Atmospheric pressure / hPa	Wind speed / m s^{-1}
TP	2019	PM_{10}	−0.143	−0.161	0.243	−0.063
		SO_2	−0.266	−0.275[(a)]	0.051	−0.027
	2020	PM_{10}	−0.235	0.190	0.249	−0.088
		SO_2	−0.430[(a)]	0.362[(a)]	0.149	−0.067
	2021	PM_{10}	−0.053	−0.484	0.401	−0.277
		SO_2	0.246	−0.349[(a)]	0.241	−0.255
IN	2019	PM_{10}	−0.540[(a)]	0.255	−0.216	−0.062
		SO_2	−0.242	−0.119	−0.150	−0.047
	2020	PM_{10}	−0.098	−0.077	0.074	0.111
		SO_2	0.149	−0.240	0.199	−0.198
	2021	PM_{10}	−0.411	−0.041	0.101	0.286
		SO_2	0.377[(a)]	−0.214	0.223	−0.133
JP	2019	PM_{10}	/	/	/	/
		SO_2	−0.140	−0.096	0.046	−0.122
	2020	PM_{10}	−0.272[(a)]	0.076	0.422[(a)]	−0.108
		SO_2	0.115	−0.290[(a)]	0.244	−0.209
	2021	PM_{10}	0.040	−0.292[(a)]	0.521[(a)]	−0.107
		SO_2	0.120	−0.425[(a)]	0.516[(a)]	−0.257

[(a)] *p*-values smaller than 0.05 are considered statistically significant.

Figure 3 shows the mean daily concentrations of SO_2 for the three monitoring stations. During the state of emergency, the concentrations of SO_2 were the highest at the measuring points TP and JP, while at the measuring point IN, the highest concentrations of this pollutant were recorded during 2021 (see Figure 3). The daily limit values were exceeded several times at measuring station JP for more than half the period in 2020. During that time, the average daily concentrations of SO_2 were even higher than 1,100 μg m^{-3}.

Mine air pollution in Bor (Serbia), which is largely due to SO_2 and PM_{10} emissions, has been a topical issue since commercial mining started in 1902. Secondary pollution could be attributed to the traffic and burning of fossil fuels from the city heating plant and domestic heating.[33] Taking into account local sources of pollution in Bor, the significant deterioration of air quality was observed during the lockdown. During the state of emergency in the city of Bor, air pollution regarding SO_2 and PM_{10} was even worse. The concentrations of SO_2 were 58 % higher compared to those in the corresponding period in 2019 and 56 % higher compared to those in 2021. The mean values of PM_{10} were 47 % higher compared to those in 2019 and 29 % higher compared to those in 2021. Although all these changes are not statistically significant, they show that air quality has not improved even though most industrial activities and the mobility of people were at the minimum level. The SO_2 and PM_{10} daily limits – 125 μg m^{-3} and 50 μg m^{-3}, respectively – have been exceeded the most times in 2020. However, apart from primary emission sources (industrial plants emissions, road traffic), long-range transport plays an important role in the air pollution problem.[34] A large peak in PM_{10} concentration (Figure 2) is visible on 26, 27, and 28 March 2020 and is similar in magnitude for all the monitoring stations. For these days, the daily average levels of PM_{10} were up to 253 μg m^{-3}. Extremely high particulate matter concentrations were recorded at automatic

Table 4. Number of days above limit values.

Period	Pollutamt	Measuring station		
		TP	IN	JP
2019	PM_{10} μg m^{-3}	1 (16)	1 (17)	/
	SO_2 μg m^{-3}	6 (53)	0 (53)	14 (53)
2020	PM_{10} μg m^{-3}	7 (50)	5 (9)	21 (53)
	SO_2 μg m^{-3}	14 (53)	0 (53)	28 (53)
2021	PM_{10} μg m^{-3}	0 (16)	4 (15)	16 (53)
	SO_2 μg m^{-3}	4 (53)	1 (53)	18 (53)

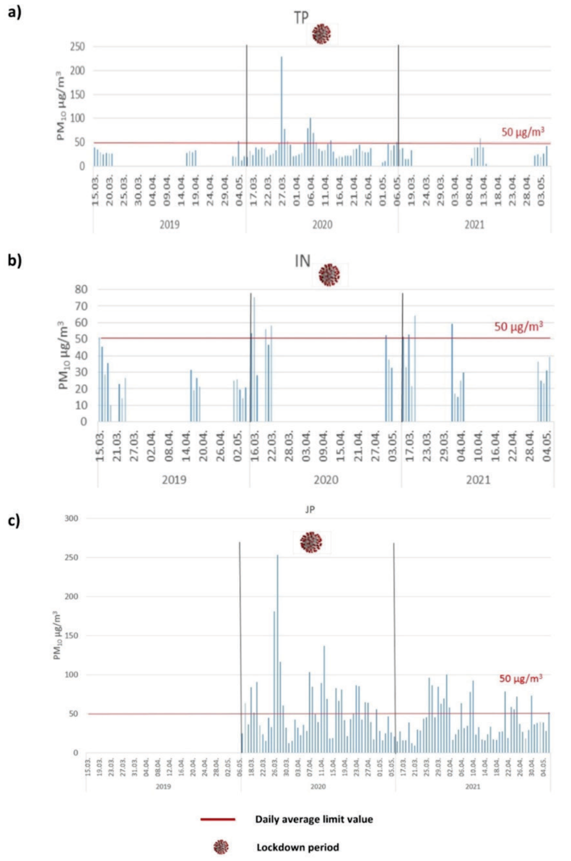

Figure 2. Daily average concentrations of PM_{10} during the three studied periods at (a) the TP monitoring station, (b) the IN monitoring station, and (c) the JP monitoring station.

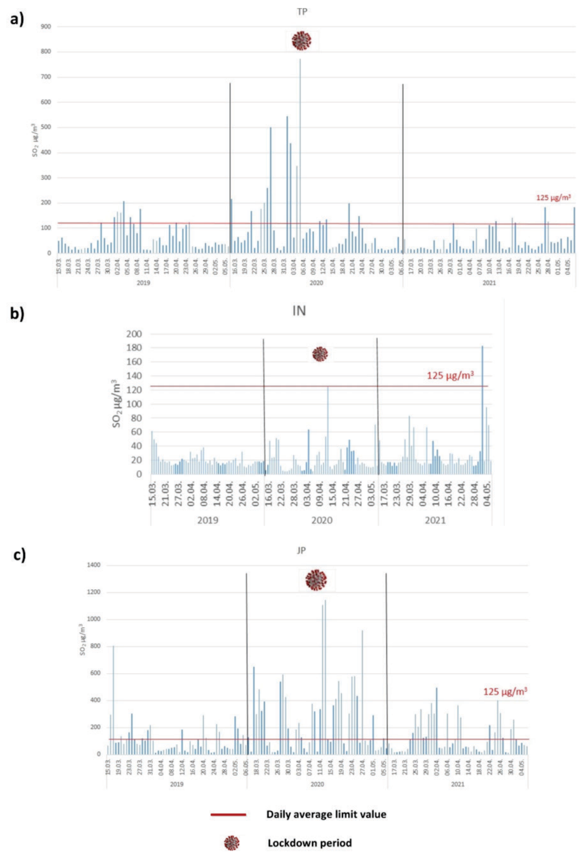

Figure 3. Daily average concentrations of SO_2 during the three studied periods at (a) the TP monitoring station, (b) the IN monitoring station, and (c) the JP monitoring station.

monitoring stations in the whole of Serbia and surrounding countries. In their paper, Davidovic et al.[29] concluded that this kind of pattern indicates some isolated event. Based on their analysis, this source of dust can be associated via back trajectory tracing to the Aralkum Desert, which is located at the Kazakhstan–Uzbekistan border.

Coincidentally, during the lockdown period, a large part of Western Europe was affected by a Saharan dust event between 26 March and 30 March (Federal Office: MeteoSwiss, 2020), and this confounded the PM climate in many European cities during this time.

Meteorological factors have a significant impact on the atmospheric environment. In analysing the lockdown's impact on the atmospheric environment, the same period on the calendar was chosen, which has already somewhat eliminated the impact of meteorological factors. However, we further statistically compare some meteorological parameters (temperature, relative humidity, air pressure, and wind speed) to analyse the potential contribution of their differences over the experimental period to changes in the atmospheric environment. The obtained results have shown that temperature and relative humidity negatively correlate with pollutants, while air pressure has a positive coefficient of correlation (except in 2019 at measuring point IN). Also, wind speed is negatively correlated with the PM_{10} concentration, which could indicate the presence of point-source pollution.[35] In addition, the results obtained in this study have shown that in 2020, the temperature was the lowest compared to that in the same period in the previous and next years, so one could conclude that more fuel was consumed, considering the fact that most people stayed at home during that period. Unfortunately, data regarding precipitation and insolation are unavailable for the study period.

The measures against spreading the SARS-COV-2 virus, introduced by most countries at the beginning of the pandemic, brought the expected results in reducing air pollution. The greatest progress has been made in terms of NO_2 concentration because the main source of NO_2 pollution is traffic, which was significantly reduced in the mentioned period. In São Paulo, significant reductions in NO_2 (54.3 %) and NO (77.3 %) were observed during lockdown compared to the five-year monthly mean.[36] On the other hand, variations in SO_2 concentration were not so significant given that many countries generally reduced emissions of this pollutant, so the impact of the measures introduced was negligible.[3,20]

However, SO_2 gas pollution is still a major issue in copper-producing countries, and the U.S. Environmental Protection Agency (EPA) has identified SO_2 as one of the six most critical pollutants. SO_2 is a gas considered a serious irritant to the upper respiratory tract given its good solubility in water and mucous membranes. It is sulfuric acid anhydride and causes chemical inflammation by reducing the defence mechanisms of the respiratory tract, lung clearance, thus facilitating the deposition and penetration of larger particles, such as PM_{10}.[37] The fact that, only during the state of emergency (53 days), the average daily concentrations of SO_2 in the city of Bor were higher than 1,000 µg m^{-3} indicates a serious problem.

Although not-so-drastic reductions in PM_{10} concentration were observed in the world (given the number of factors that have an impact on its concentration), even in the most polluted parts of the world – such as India,[38,39] China,[40] and Iraq[2] – a significant improvement in air quality compared to the concentrations of this pollutant was noted. On the other hand, some papers have reported even greater concentrations of PM_{10} during the lockdown. A study conducted in Spain[41] showed that although PM_{10} emissions were reduced, meteorological conditions contributed to increased concentrations in the observed period. Also, increased concentrations of PM_{10} during the first weeks of lockdown in Colombia were caused by forest fires in the northern part of South America.[42,43] Other studies which have shown significant reductions in concentrations of PM_{10} during the COVID-19 lockdown have often been conducted in megacities that present a very different urban environment compared to Bor.[11,44] The main source of pollution in Bor is the copper smelter, whose activity did not stop during the state of emergency, so along with other sources (domestic heating, heating plant, long-range transport), it contributed to increased pollution during the lockdown period. Furthermore, the fact that SO_2 and PM_{10} levels exceeded WHO daily limit values suggests that stationary sources from the industrial sector with fossil fuel burning played a significant role in the complex source mix.[45] In Almaty, a similar case was recorded, where the contribution of non-traffic sources was attributed to the exceeding levels during the lockdown period.[5]

CONCLUSIONS

In this paper, the air quality during lockdown was analysed, and the results were compared with the corresponding periods in 2019 and 2021. The results revealed that the average daily concentrations of PM_{10} and SO_2 were even higher in 2020. However, these results are different from those of many previous studies, which reported reductions in the concentrations of the observed pollutants. For this reason, the assumption that reducing the frequency of traffic and certain economic activities would contribute to a significant improvement in air quality is completely wrong. This is true primarily in terms of NO_2 concentrations, but the problem of air pollution with other, much more dangerous pollutants for human health would still not be solved in this manner. Therefore, the cooperation of all actors (policy, economy, science) is important to find a sustainable solution to the air pollution problem in urban environments.

The main limitation of this paper is that only six variables were studied. Many other variables could potentially have affected the air quality during the studied period. Unfortunately, more information on other pollutants – such as O_3, NO_2, CO, and $PM_{2.5}$ – were unavailable for the study period. Despite this limitation, the obtained findings could be used as a basis for future studies on this topic.

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