

IMPACT OF LOCKDOWN ON AIR QUALITY IN BELGRADE DURING COVID-19 PANDEMIC

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The Environmental Protection Agency of the Republic of Serbia continuously monitors and collects air quality parameters at numerous measuring points throughout the country. The results revealed that the levels of air pollution recorded during the lockdown differed from those recorded during the same period the previous years. In this paper, we examined pollutant concentration trends in 2020 and a few previous years to determine the underlying causes of these trends. Pollutants are measured at five stations in Belgrade from the beginning of March to the end of July between 2015 and 2020. Because no hourly data were available, nitrogen dioxide, sulphur dioxide, and suspended particles PM_{10} and $PM_{2.5}$ are average daily values, whereas carbon monoxide and ozone are daily 8-hour maximums. Concentrations were compared and averaged only when data for the same period over time was available, i.e. when comparing 2020 to previous years. The results were compared to the annual and daily limit values (for ozone and carbon monoxide 8h maximums, respectively), as well as the variations in concentrations over time. The goal of calculating and displaying these values is to specifically identify a change in air pollution during the COVID-19 virus pandemic isolation period.

In general, for Belgrade in 2020, NO_2 concentrations are lower at four stations; $PM_{2.5}$ concentrations are lower at two stations; PM_{10} concentrations are higher at one station and lower at another; and SO_2 concentrations are higher than in previous years (2015-2019).

Key words: air pollution, COVID-19, lockdown

1. Introduction

The most common air pollutants in ambient air include particulate matter (PM_{10} and $PM_{2.5}$), ozone (O_3), nitrogen dioxide (NO_2), carbon monoxide (CO), and sulfur dioxide (SO_2). Particulate matter (PM), tiny airborne particles that adsorb polycyclic aromatic hydrocarbons (PAHs), heavy metals, and other volatile organic fragments, can be inhaled into the human lungs and cause lung disease, but can also enter the bloodstream and cause cardiovascular disease. Black carbon (BC) is a part of particulate matter produced by incomplete combustion and has been associated with carcinogenic effects in humans [1]. Nitrogen dioxide is a gaseous air pollutant composed of nitrogen and oxygen that is formed when fossil fuels such as coal, oil, gas, or diesel are burned at high temperatures. Nitrogen dioxide damages the lungs in several ways, including by aggravating coughing

and wheezing, limiting lung function, increasing asthma attacks, and increasing the likelihood of emergency room and hospital visits. According to recent research, NO₂ is likely a contributing factor to asthma in children. Sulfur and oxygen combine to form sulfur dioxide, a gaseous air pollutant. SO₂ is formed when fuels containing sulfur, such as coal, oil, or diesel, are burned. Sulfates, which contribute significantly to particulate pollution, are also produced by sulfur dioxide in the atmosphere. Electricity generation, commercial boilers, and other industrial processes such as metal processing and petroleum refining are the main sources of sulfur dioxide emissions. Another major source of diesel emissions is from aging busses and trucks, locomotives, ships, and off-road diesel machinery. Sulfur dioxide has a number of harmful effects on the lungs, including wheezing, shortness of breath, chest tightness, and other problems, especially during physical exertion [2].

Air pollution comes from mobile (cars, buses, planes, trucks, and trains), stationary (power plants, oil refineries, industrial plants, and factories), spatial (agricultural land, cities, and wood-burning sites), and natural (windblown dust, forest fires, and volcanoes) sources. It is a global health and environmental problem, and one of the biggest problems in the world that seriously threatens human health. According to the World Health Organisation (WHO), more than 7 million deaths are attributed to air pollutants each year [1]. The trend of increasing urban population and energy consumption as well as traffic volume has led to a significant increase in air pollution. For this reason, air pollution is being studied in many countries and various solutions are being sought to reduce it.

The emergence of the Sars Cov2 virus in the world has caused significant disruptions in the operations of many countries and cities. On March 11, 2020, the World Health Organization (WHO) declared a global coronavirus pandemic (Sars Cov2) [3]. The high number of infections and deaths compelled many governments to implement drastic locking measures to prevent virus spread, particularly at the start of the pandemic, until the first vaccines became available. During the lockdown, traffic density was greatly reduced, and human activities were greatly restricted. The emergency rules reduced human activities but provided a new perspective for studying air pollutants and understanding how human activities contribute to them.

This study was conducted primarily by comparing the values of the major pollutant concentrations during the lockdown and in previous periods: immediately before, during, and after closure, or by comparison with previous years in the same period.

Concentrations of particulate matter (PM_{2.5} and PM₁₀), and CO were measured at six stations in the Victoria, Mexico [4] area, four weeks before and twelve weeks after partial closure. There was a significant decrease in concentrations. The air quality in Poland as a whole was investigated [5]. NO₂ was measured using satellite data, and NO₂, PM, and SO₂ were measured using station data. Three months were observed: March, April, and May, with significant reductions compared to 2018 and 2019. The concentrations of PM_{2.5}, PM₁₀, and NO₂ were compared during the lockdown period to previous data from four Indian megacities (Delhi, Pune, Mumbai, and Ahmedabad) [6]. Significant reductions in NO₂ concentrations (60-65%) and relatively lower reductions in PM_{2.5} (25-50%) and PM₁₀ (36-50%) were observed.

During March-May 2020, a combination of aerosol (PM_{2.5}) and gases (NO₂, SO₂, CO, and O₃) data, as well as meteorological datasets (MT, RH, AP, WS, and RainF), were collected from ground and satellite-based stations in Dhaka, Bangladesh [7]. PM_{2.5} and NO₂ levels fell by 26-54.2% and 20.4-55.5% in the urban city area during full and partial lockdowns, respectively, when compared to the pre-lockdown period.

The review of lockdown measures in 19 countries (South and Southeast Asia region) [8], as well as a spatial-temporal analysis of the effect of pandemic mitigation measures on regional-scale air quality. Overall air quality in the study area improved significantly during the lockdown, with at least 50% of the study area experiencing a significant reduction in atmospheric NO₂, SO₂, and PM_{2.5}. In 80% of the study area, the concentration of O₃ increased unexpectedly.

Paper [9] investigates air pollution data from 162 monitoring stations in 12 cities from COVID-19 affected countries: concentrations of PM_{2.5} and PM₁₀, NO₂, SO₂, and O₃ were analysed during March, April, and May of 2020 and compared to the same time frame in 2019. Because of the restricted emissions during the lockdown phase, the major pollutants, including PM_{2.5}, PM₁₀, and NO₂, have shown a remarkable reduction in the post-lockdown period compared to the pre-lockdown period for all selected locations. Similarly, the concentrations of these pollutants were significantly lower in March, April, and May of 2020 compared to the same months in 2019. During the lockdown phase, the SO₂ concentration level showed a mixed trend. In a few cities, such as Lima, Madrid, Moscow, Rome, Sao Paulo, and Wuhan, SO₂ concentrations remained unchanged during the lockdown period because the main source of SO₂ emissions is power plants, which remained operational in most cases. Many locations' O₃ concentration levels increased during the lockdown phase, which could be attributed to a reduction in O₃ consumption during the titration process and changes in meteorological conditions over time. Similar findings have been reported in Saudi Arabia [10], northern India [11], Wuhan, China [12], Rio de Janeiro [13], and Sao Paulo, Brazil [14].

In Portugal [15], data from 24 air quality monitoring stations, including rural, urban background, and 11 urban traffic air quality monitoring stations, were considered for NO₂ and PM₁₀. NO₂ and PM₁₀ had average reductions of 41% and 18%, respectively. The authors concluded that NO₂ and PM₁₀ reductions occurred primarily in urban areas, with traffic contributing more than 60% of NO₂ concentrations.

Measuring was done at 15 monitoring air quality stations in New York City [16]. There are no significant differences in NO₂ and PM_{2.5} concentrations between the first 17 weeks of 2015 and 2020. The analysis could account for both short- and long-term changes in air quality, and New York City has lower baseline concentrations of air pollutants than the other locations under consideration. Similar findings were obtained in Northern South America [17], Madrid and Barcelona, Spain [18], and the continental United States [19]. Some authors [20-24] also addressed the impact of meteorological conditions on air pollution during the pandemic. The question arises whether the COVID-19 pandemic contributed to the reduction of air pollution in Belgrade and thus made a positive contribution.

The declaration of a COVID-19 epidemic in Serbia on March 20, 2020, has had a significant impact on the operation of many systems. To prevent the spread of the infection, the Government of the Republic of Serbia imposed and lifted a number of restrictions, including complete bans on the movement of people over the age of 65, restrictions during specific times, closures of restaurants, cafes, shopping malls, and markets, restrictions on passenger bus transportation, restrictions on domestic and international passenger rail traffic, and so on. Kindergartens, schools, and colleges were also closed. Public organizations now handle emergencies and conduct business online. (e.g. social services). The majority of companies now allow employees to work from home. As a result of all of this, there has been significantly less human movement and consumption across a variety of industries.

This study's objective is to demonstrate how the concentrations of major pollutants changed from 2015 to 2019 to the locking period. The results obtained can serve as a guide for decision-makers to implement specific measures in order to accomplish the objectives related to the reduction of air pollution.

2. Methodology

The Environment Protection Agency (SEPA) of the Republic of Serbia [25] continuously monitors air quality parameters throughout the country and collects data from the local network monitoring system. For this paper, we used data from SEPA measuring stations in Belgrade, Serbia. (Fig. 1). By analysing all data available from the local SEPA network monitoring system, measurement periods with or without data are classified. (Table 1.). The analysis includes data from automatic monitoring stations for major pollutants (CO, NO₂, O₃, PM_{2.5}, PM₁₀, SO₂) and meteorological parameters (t, RH, wind speed, wind direction) collected in Belgrade from the five automatic monitoring stations: Mostar, Novi Beograd, Stari grad, Vračar, and Zeleno brdo.

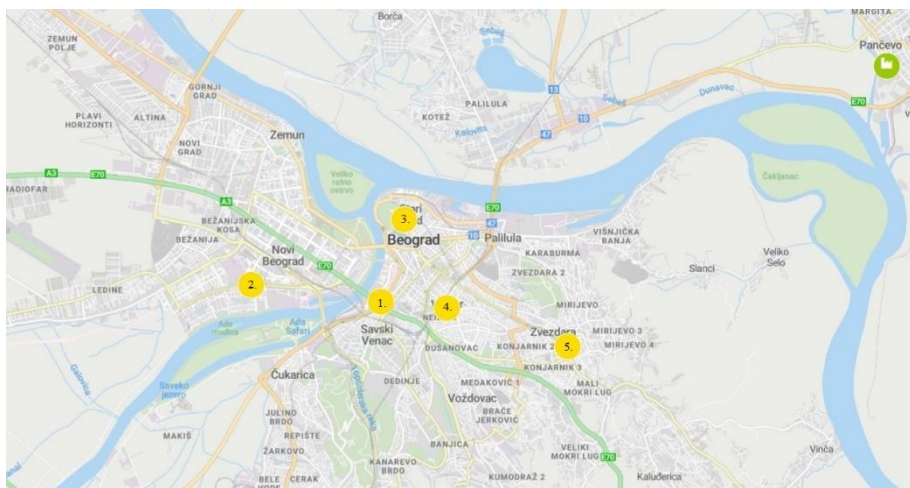


Figure 1. SEPA measuring stations in Belgrade used for this paper

In this section, we compare ambient NO₂, SO₂, PM₁₀, and PM_{2.5} air pollutant concentrations during COVID-19 lockdown between May and July 2020, compared to concentrations in Belgrade from the previous 5 years for the same period.

Table 1. Data availability pollutants and years for each measuring station

Measuring station/National Code	Year	Pollutant					
		CO	NO ₂	O ₃	PM _{2.5}	PM ₁₀	SO ₂
1. Mostar (urban/traffic) RS0028A	2015	-	√	√	-	-	√
	2016	-	√	-	-	-	√
	2017	-	√	-	-	-	√
	2018	√	√	-	-	√	√
	2019	√	√	-	√	√	√
	2020	√	√	-	√	√	√
2. Novi Beograd (urban/background) RS0036A		CO	NO ₂	O ₃	PM _{2.5}	PM ₁₀	SO ₂
	2015	√	√	-	-	-	√
	2016	-	√	-	√	√	-
	2017	√	-	-	-	-	√

	2018	√	-	√	-	-	√
	2019	√	√	√	√	√	√
	2020	√	√	√	√	√	√
		CO	NO ₂	O ₃	PM _{2.5}	PM ₁₀	SO ₂
3. Stari grad (urban/background) RS0032A	2015	√	√	-	-	-	-
	2016	√	√	-	√	√	-
	2017	√	-	√	-	-	-
	2018	√	-	√	√	√	-
	2019	√	√	√	√	√	-
	2020	√	√	√	√	√	-
		CO	NO ₂	O ₃	PM _{2.5}	PM ₁₀	SO ₂
4. Vračar (urban/background) RS0037A	2015	√	√	-	-	√	-
	2016	√	√	-	-	-	-
	2017	-	√	-	-	√	-
	2018	-	√	√	-	√	√
	2019	-	√	√	-	-	√
	2020	-	√	√	√	√	√
		CO	NO ₂	O ₃	PM _{2.5}	PM ₁₀	SO ₂
5. Zeleno brdo (suburban/background) RS1027A	2015	-	√	√	-	√	√
	2016	-	√	-	-	-	√
	2017	-	√	-	-	-	√
	2018	-	√	√	-	-	√
	2019	√	√	√	-	-	√
	2020	√	√	√	-	-	√

There were significantly fewer measurements taken in 2017 and 2018 than in 2019 and 2020, both by pollutants and by stations. As a result, some pollutants were unable to compare measuring results from 2020 during the lockdown period to previous years during the same time period.

3. Results and discussion

- Nitrogen dioxide (NO₂)

At all monitoring stations in Belgrade, the annual limit value for nitrogen dioxide of 40 µg/m³, as well as the daily limit value for NO₂ of 85 µg/m³ [26] has not been exceeded during the observed period in 2020. Due to a lack of data, it is not possible to analyse the NO₂ concentration for the observed period in earlier years in some stations. It has been noticed that the average value of NO₂ for the observed period from March the 1st to June the 30th in 2020 is 38% lower compared to 2019 and for years 2018/2017/2016/2015 respectively by 41%/16%/54%/38%.

In Fig. 2, presented graphs show difference between NO₂ concentration daily values averaged for five years 2015-2019 and values in 2020. Comparing NO₂ concentration average value for five years from 2015 to 2019 (each year period from 1st March to 30th June) with concentration in 2020 (the same period of year), decrease of 41% is recorded. Similar results have been confirmed also by several studies worldwide [27,28,29]. The obtained results are expected considering the reduced intensity of traffic in the city during lockdown. The differences are more pronounced in urban measuring stations, with the smallest difference observed at station 5, which is located in a suburban area with low traffic.

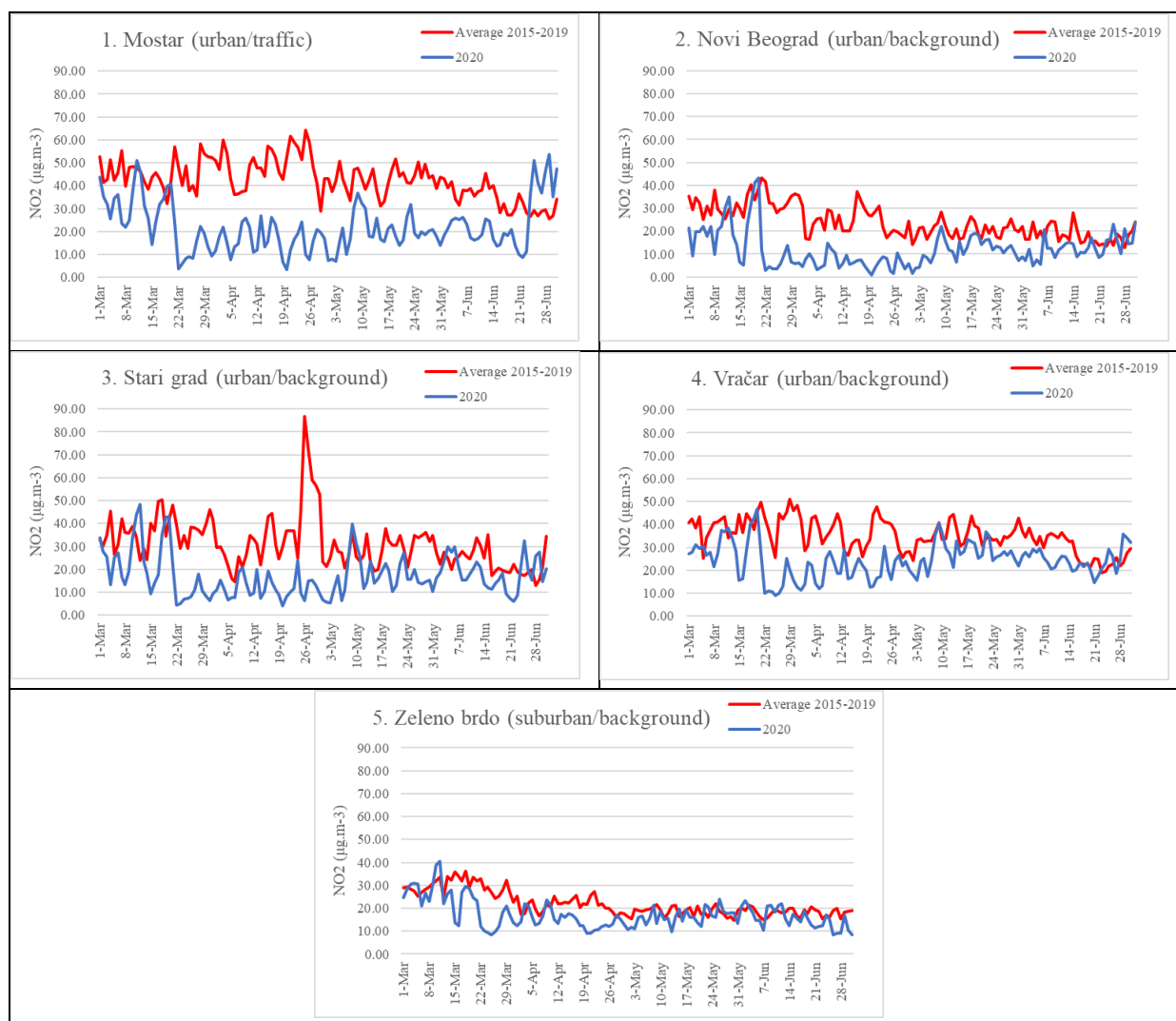


Figure 2. NO₂ concentrations recorded

- Sulfur dioxide (SO₂)

SO₂ concentrations were measured at four stations in Belgrade. During the observation period, no station in Belgrade exceeded the annual limit value for sulphur dioxide of 50 µg/m³ and daily limit value of 125 µg/m³ [26]. The highest SO₂ concentrations were recorded in 2020, compared to previous years, at all Belgrade stations except station 1, but they are below the allowable limit values. It is believed that the cause of the increased value of SO₂ concentration in 2020 compared to previous years comes from coal used in a nearby thermal power plant. The highest average annual SO₂ concentration was measured at station 5 in 2020 when compared to other years in the observed period. There are numerous private house individual furnaces in the vicinity of this station. It is assumed that during the lockdown, the burning of coal and biomass increased the concentration of SO₂ at this location significantly.

In comparison with the same period of time (2015–2019), daily average SO₂ concentrations shown in Fig. 3 recorded an increase of 32%, 42% and 103% at the stations 2, 4 and 5 respectively. Only at station 1 was recorded a decrease of 18% in concentration to the previous years.

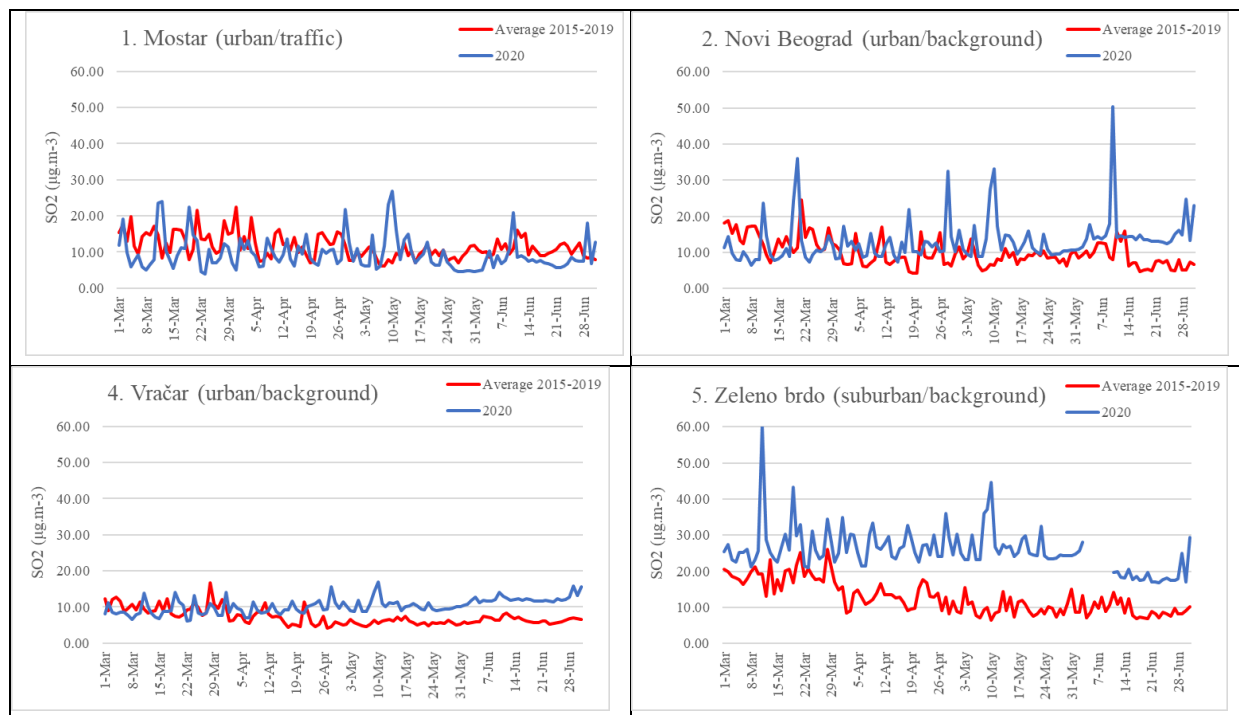


Figure 3. SO₂ concentrations recorded

- Particulate matter (PM₁₀)

In Belgrade, the annual limit value for PM₁₀ (40 g/m³) was not exceeded at any of the monitoring stations during the observed period in 2020. The analysis of average annual concentration data for PM₁₀ revealed that the highest concentration was recorded in 2020 (except for the station 4), which is 12% higher than in 2018 and 15% higher than in 2019 at station 3. On the other hand, the average annual values of PM₁₀ in 2020 were 3% higher than in 2019 and 29% higher than in 2018 at station 1, which is located in a traffic-heavy area. The daily limit value of PM₁₀ concentration (50 µg/m³) [26] was exceeded for the observed period in earlier years and in 2020 also (Fig. 4).

At the end of March (the 27th March 2020) a sudden increase of PM₁₀ concentration has been recorded at all station. The following text provides an explanation for this phenomenon.

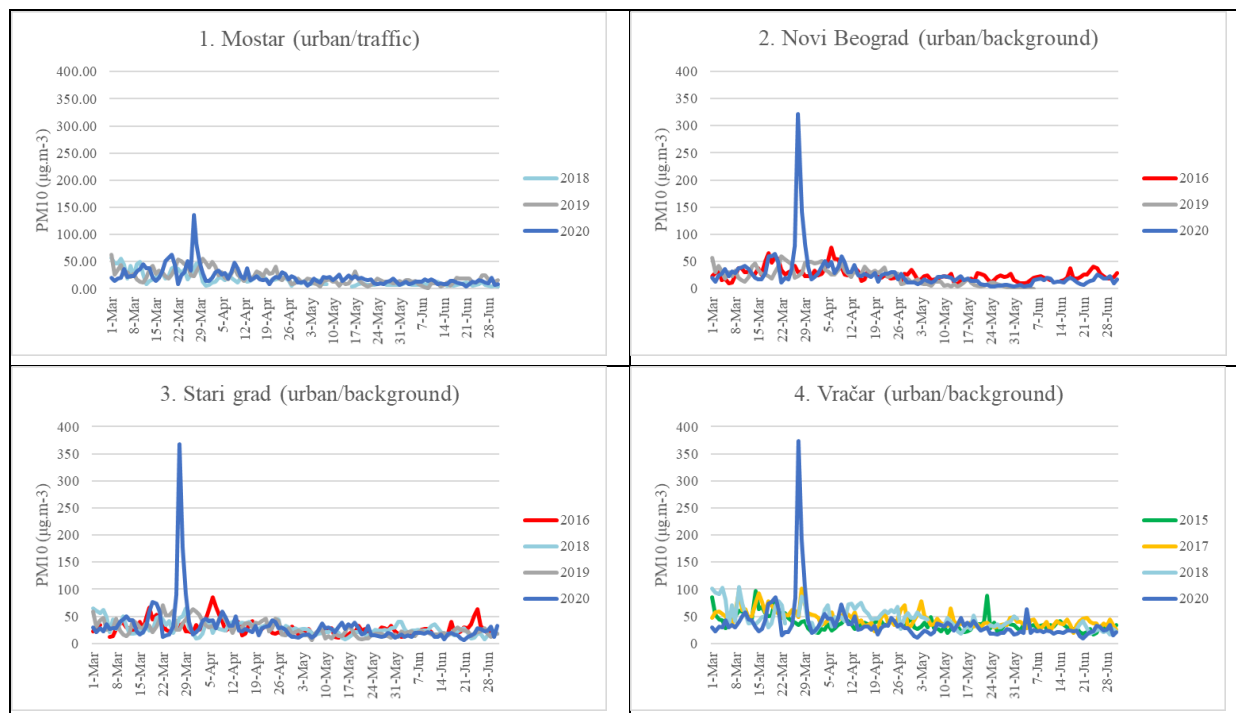


Figure 4. PM₁₀ concentrations recorded

- Fine particulate matter (PM_{2.5})

The annual limit value for PM_{2.5} concentration ($25 \mu\text{g}/\text{m}^3$) has not been exceeded over the observed period in earlier years and in 2020 as well. Average annual concentration data analysis has shown slightly lower concentration of PM_{2.5} in 2020, which is 0.4%, 0.3% and 3% lower compared to 2019 at the stations 1,2 and 3, respectively. At the end of March, similar to the PM₁₀ concentrations, two peaks have been recorded (Fig. 5).

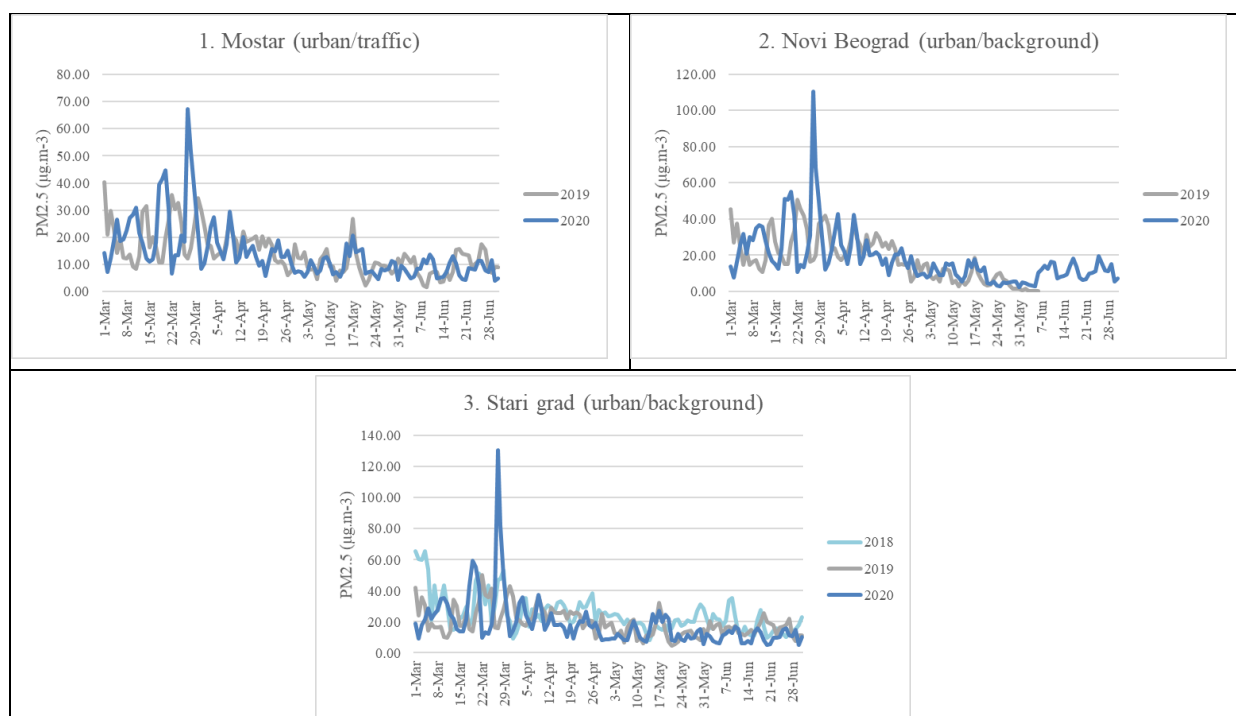


Figure 5. PM_{2.5} concentrations recorded

During the observed period, daily limits were exceeded at the majority of stations. On March 27, 2020, the Aralkum desert was identified as the external source of a significant increase in PM in Serbia and other countries in South-East Europe [30].

In 2020, the lowest concentrations of suspended $PM_{2.5}$ and PM_{10} particles were recorded at all Belgrade stations, compared to previous years. PM_{10} and $PM_{2.5}$ are two of the most common air pollutants in cities, both of which are produced by combustion processes (exhaust gases from internal combustion engines, fly ash from thermal power plants, and individual combustion furnaces). The higher measured average values in 2020 for all stations are thought to be due to traffic in central city municipalities and busy roads.

It was assumed that the restriction of movement would primarily result in a change in pollution caused by traffic. That is why nitrogen dioxide concentrations were analysed. Suspended particles, which are constantly present in the atmosphere and are the leading cause of pollution in the Republic of Serbia, were also studied.

Other sources of emissions, such as agricultural activity and heating during the winter, are certainly significant when it comes to emissions, and the state of emergency was mostly during the heating season.

Significant differences occurred in the mean daily values, which showed a drop when compared to 2019. The most noticeable differences were at stations 3 and 2, as well as at station 1, which monitors pollution caused by traffic. The percentage drop in mean concentrations ranged from 52% to 65% at the stations listed.

During the state of emergency, suspended PM_{10} particles exceeded the daily limit value of $50\mu g/m^3$ at the following stations: 1 (20 days) and 3 (16 days).

By comparing the mean values of PM_{10} during the entire period of the state of emergency with the same period in 2019, there is an increase in the average value in 2020, which is insignificant at the station 1, and for stations 2 and 3 significant difference was recorded.

In contrast to concentrations of nitrogen dioxide, concentrations of PM_{10} increased during the state of emergency compared to the same period in 2019. An episode of high PM_{10} concentrations occurred in the period 26th-29th March in Hungary, Bulgaria, Serbia, Croatia, Slovenia and part of Italy when, as mentioned in some sources, the analysis of HYSPLIT images showed that the source of pollution was a sandstorm in the Aralkum desert, on the border of Kazakhstan and Uzbekistan (Fig. 6).

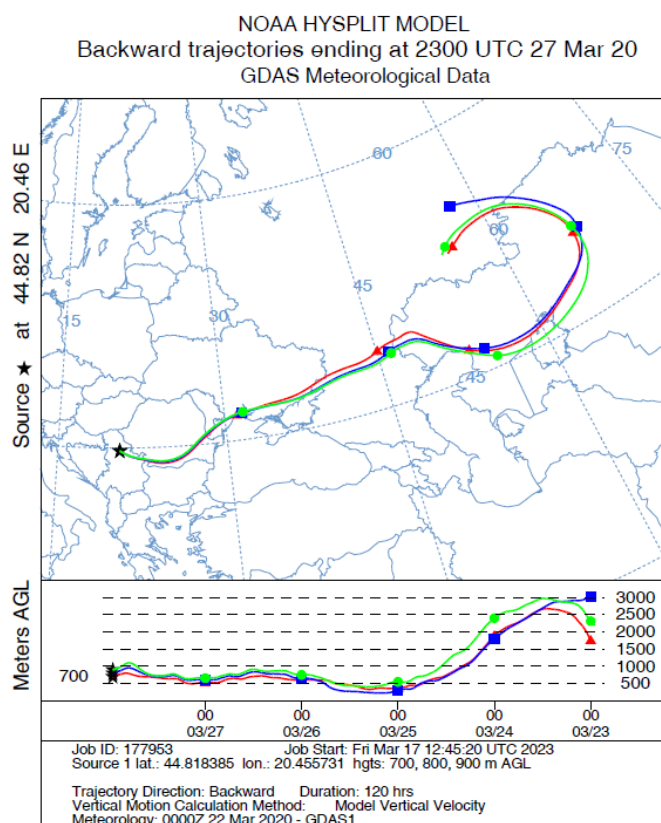


Figure 6. NOAA Hysplit backward model

The day with the highest recorded concentrations was March the 27th.

4. Conclusion

The impact of declining human activity during the COVID-19 pandemic on air pollution is investigated in this paper. The measured values of ambient air pollutant concentrations in Belgrade during the COVID-19 lockdown (data obtained from the Environmental Protection Agency of Serbia) were analysed between May and July 2020. The analysis was carried out by comparing the measured concentrations of pollutants NO_2 , SO_2 , PM_{10} , and $\text{PM}_{2.5}$ for the period May-June 2020 to previous years' concentrations for the same period.

The main causes of pollution are local combustion plants, heating and thermal power plants that use coal and fuel oil as the primary fuel for combustion. The state of emergency caused by the

emergence of the COVID-19 infection undoubtedly had an impact on nitrogen dioxide concentrations, which fell, but the cause of pollution by suspended particles is far more complex, so a clear picture of the impact was not obtained. Furthermore, an unusual sandstorm in the Aralkum desert, which was attributed to a spike in the concentration of suspended particles in Kazakhstan, Uzbekistan, Hungary, Serbia, Croatia, and Slovenia on March 27 at the most, contributed to the increase in mean PM₁₀ concentrations for the observed period.

Apart from heat and power generation, there are no large industrial areas in Belgrade that could contribute to increased pollution in the city. It can be concluded that the greatest pollution comes from nitrogen dioxide caused by urban traffic, and that this is the sector where measures to reduce pollution would achieve the best results.

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