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Air quality during SARS-CoV-2 (COVID-19) lockdown in Sarajevo

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ABSTRACT

The aim of this paper is to compare air quality in Sarajevo in March 2019 and March 2020 with outbreak of the novel coronavirus SARS-CoV-2 in Sarajevo and Bosnia and Herzegovina. First preventive and protective measures were issued at the end of second week of March, while on 21 March 2020 an order imposing complete ban of movement of citizens from late afternoon until early in the morning next day was issued. This was rare opportunity to compare air quality in Sarajevo having same causes of air pollution for one part of March 2019 and March 2020 and different causes of air pollution during the lockdown and ban of movement caused by SARS-CoV-2. Statistical hypothesis testing is used to compare values during March 2019 and March 2020 before the lockdown (the first phase) and during the lockdown (the second phase). Complete and comprehensive analysis is performed for both phases of March 2019 and March 2020, before the lockdown and during the lockdown. It is shown that there are statistical evidences that during the lockdown period mean concentration values of O_3 and NO_2 are smaller than mean values during the same period in March 2019, while mean concentration value of PM_{10} is greater than mean value during the same period in March 2019. Also, statistical hypothesis testing is used to compare concentration of air pollutants before and during lockdown period in March 2020. It is shown that mean concentration values of PM_{10} and O_3 are greater during lockdown period, while mean concentration value of NO_2 before the lockdown in March 2020 is greater than during the lockdown period. Coefficients of correlation as the measure of the strength of linear association between air pollutants PM_{10}, O_3 and NO_2 and meteorological parameters air temperature, humidity and pressure, wind speed and wind direction are calculated as well.

Keywords: SARS-CoV-2, COVID 19, air quality, hypothesis testing, lockdown

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1. Introduction

Although the first case in Bosnia and Herzegovina of a person infected by SARS-CoV-2 was registered on 05 March 2020 in town of Banja Luka, located around 200 km north-west from Sarajevo, in Sarajevo, the capital of Bosnia and Herzegovina, all activities of citizens were performed as usual almost during full first two weeks of March 2020. By the end of the second week of March schools and universities in Sarajevo were closed. During the weekend days 16 and 17 March relevant state authorities made appeal to citizens to stay at home. On 17 March 2020 the Federal Headquarter for Civil Protection issued an order regarding the temporary closure of service businesses like restaurants, fast food businesses, cafes, pastry shops etc. Also, on 17 March 2020 the Federal Headquarter for Civil Protection issued an order of temporary closure of cinemas, museums, theaters, concert halls, art galleries, public swimming pools, sport centers etc. On 19 March 2020 an order of the Federal Headquarter for Civil Protection was issued to ban public transportation on the territory of Federation of Bosnia and Herzegovina, except taxi vehicles. Based on these orders of the Federal Headquarter for Civil Protection, closure of the schools and universities and respecting the appeal of the relevant state authorities to the citizens to stay at home, much less people and cars could be observed on the streets of Sarajevo. The first case of a person infected by SARS-CoV-2 in Sarajevo was registered on 20 March 2020.

On 21 March 2020 Federal Headquarter for Civil Protection issued an order imposing complete ban of movement of citizens of Federation of Bosnia and Herzegovina from 06:00 pm until 05:00 ordering citizens to stay at home during that time period. On 29 March 2020 this ban of movement of citizens was reduced by two hours and lasted from 08:00 pm until 05:00 am.

Thus, from 22 March 2020 at 00:00 until the last day of March 2020 at midnight strict ban of movement was imposed from 06:00 pm until 05:00 am, with exception of a few last days of March when the ban of movement was from 08:00 pm until 05:00 am. During the ban of movement citizens were not allowed to go out of their homes, and there were no cars on the streets except those with special permission, police, ambulance, fire service vehicles etc. Also, since almost all non-essential shops were temporarily closed, less people could be seen on the streets and less vehicles were observed on the streets of Sarajevo during the daytime.

Since Sarajevo is in chronic state of a very bad air quality for years during the extended winter and heating season this was ideal situation to compare air quality in March 2020 with air quality in March 2019. Having in mind the order of ban of movement of citizens it was logical to divide March 2020 into two phases.

The first phase lasted from 01 March 2020 at 00:00 until 22 March at 00:00 for both 2019 and 2020. Assumption for the first phase is the stability of the system. Stability of the system, with regard to air pollution, assumes that same causes of air pollution that existed during first phase of March 2019 existed during the first phase of March 2020. The second phase lasted from 22 March 2020 at 00:00 until 01 April at 00:00 for both 2019 and 2020. It is important to notice that the stability of the system regarding air quality could not be applied for the second phase of March, since in the second phase of March 2020 order on ban of movement of citizens out of their homes was implemented and causes of air pollution that existed during second phase of March 2019 did not exist during the second phase of March 2020.

Design of the research in this paper corresponds to the dramatic change of the situation during March 2020 due to SARS-CoV-2 outbreak. For that reason, data regarding air pollution were compared for the first and second phase of March 2019 and March 2020, and separately for the second phase of March 2019 and March 2020. Also, statistical hypothesis testing is used to compare concentration of air pollutants before and during lockdown period in March 2020.

Sources of air pollutants and their impact on concentration of that pollutants in the air are not considered.

Values of air pollutants: PM_{10} [$\mu g/m^3$], O_3 [$\mu g/m^3$] and NO_2 [$\mu g/m^3$] as well as values of meteorological parameters: temperature [^oC], pressure [hPa], humidity [%], wind speed [m/s] and wind direction for March 2019 and March 2020 were obtained from the Federal Hydrometeorological Institute from Sarajevo. The data consist of hourly values of each air pollutant and each meteorological parameter for each day during March 2019 and March 2020. The data were divided into two parts that corresponds to the dates of the first and the second phase as explained above.

Measures taken to isolate citizens and reduce movement result in a very small number of COVID-19 positive cases in Sarajevo. The emergence of the Sars-Cov-2 virus occurred at a time when pollution in Sarajevo within normal limits. However, it can be concluded from the literature that increased air pollution in certain parts of the world has an impact on the average COVID-19 deaths. It was shown in [1] that long-term exposure to increased concentration of $PM_{2,5}$ leads to increased mortality. Edoardo et al. in [2] examined the correlation between high mortality rates of COVID-19 and air pollution in northern Italy. It has been shown that high levels of pollution should be taken into consideration when analyzing mortality. The effect of increased air pollution on respiratory infections was examined in [3] where it was concluded that increased air pollution causes respiratory infections.

Due to the introduced quarantine measures, this paper focuses on analyzing the changes in air pollution in Sarajevo. The change in high air quality isolated in Barcelona was examined in [4] and it was concluded that the concentration of NO_2 and BC was decreased, the concentration of PM_{10} was slightly decreased and the concentration of O_3 was increased by 50%. It was also shown in [5] that the concentration of NO_2 and CO_2 pollutants are significantly lower during quarantine caused by COVID-19.

2. Data analysis

For both the first and the second phases of March 2019 and March 2020 concentrations of each air pollutant are graphically depicted. Comprehensive descriptive statistics results of air pollutants are presented in tables also for both phases, and correlation coefficients between air pollutants and meteorological parameters for both phases are computed as well.

Graphical presentation of concentration of air pollutant PM_{10} for the first phase of March 2019 and the first phase of March 2020 is shown at Fig. 1.

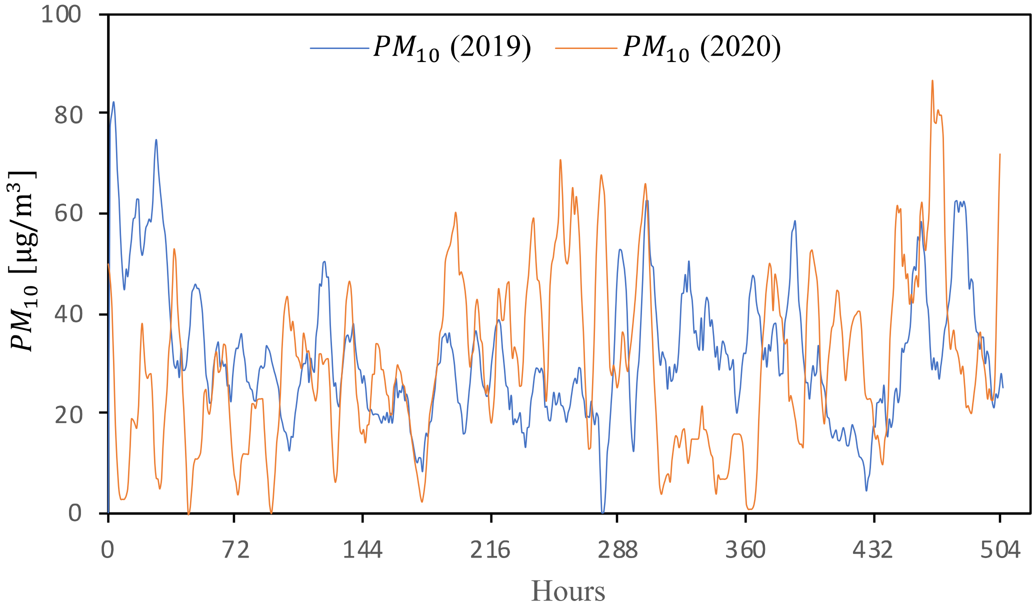

Figure 1. Concentration of PM_{10} for the first phase in March 2019 and March 2020

Graphical presentation of concentration of air pollutant O_3 for the first phase of March 2019 and the first phase of March 2020 is shown at Fig. 2.

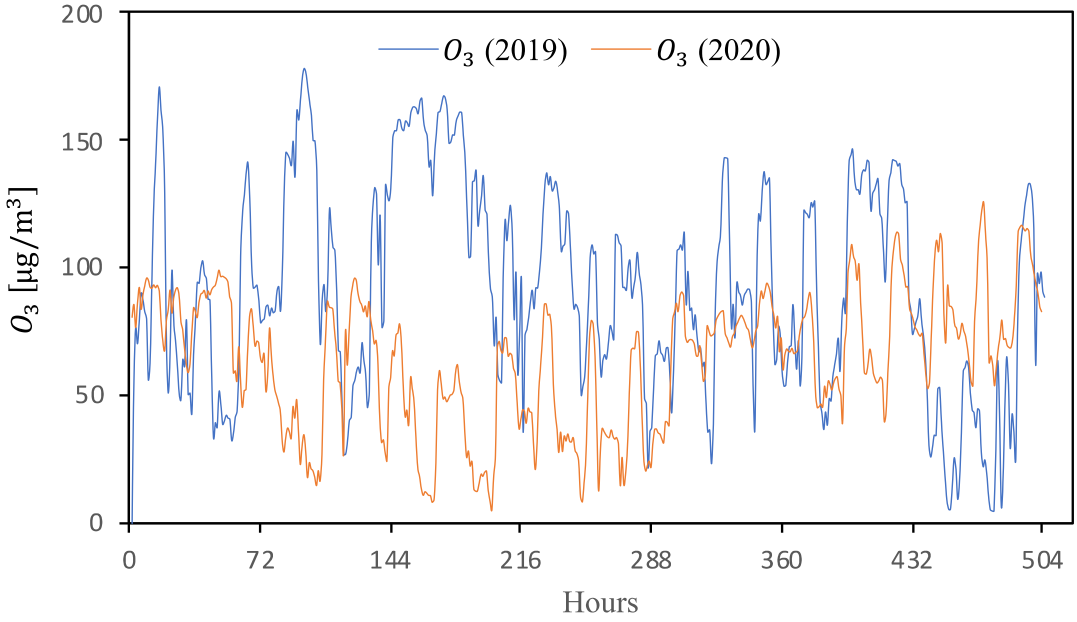

Figure 2. Concentration of O_3 for the first phase in March 2019 and March 2020

Graphical presentation of concentration of air pollutant NO_2 for the first phase of March 2019 and the first phase of March 2020 is shown at Fig. 3.

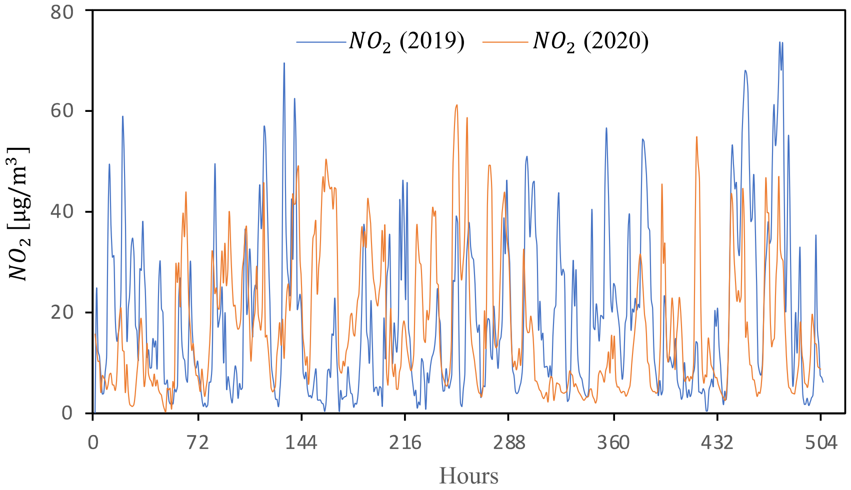

Figure 3. Concentration of NO_2 for the first phase in March 2019 and March 2020

Graphical presentation of concentration of air pollutant PM_{10} for the second phase of March 2019 and the second phase of March 2020 is shown at Fig. 4.

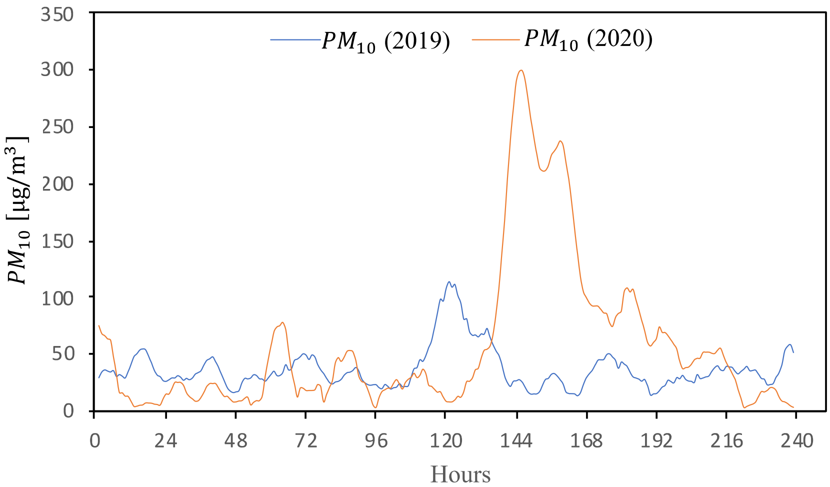

Fig. 4. Concentration of PM_{10} for the second phase in March 2019 and March 2020

Graphical presentation of concentration of air pollutant O_3 for the second phase of March 2019 and the second phase of March 2020 is shown at Fig. 5.

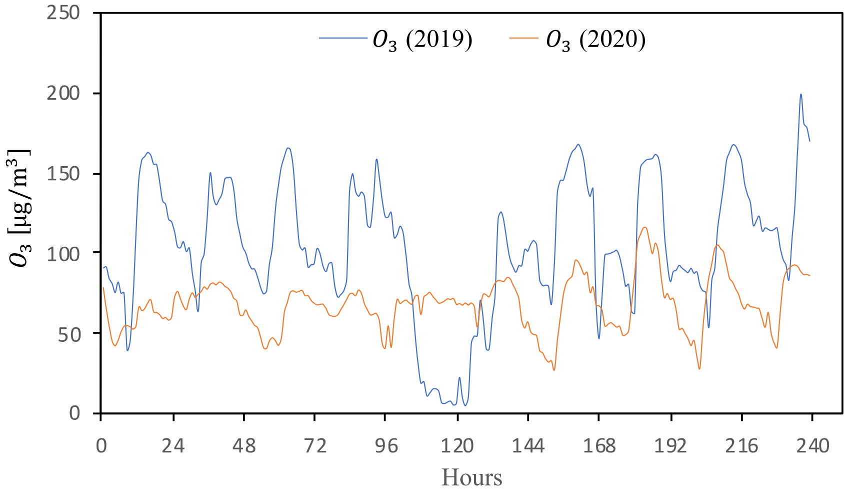

Figure 5. Concentration of O_3 for the second phase in March 2019 and March 2020

Graphical presentation of concentration of air pollutant NO_2 for the second phase of March 2019 and the second phase of March 2020 is shown at Fig. 6.

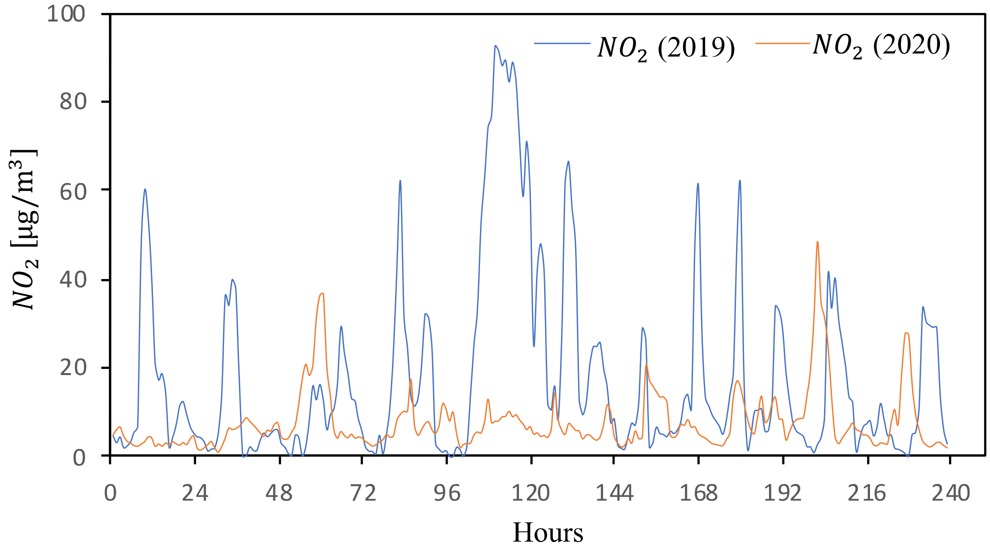

Figure 6. Concentration of NO_2 for the second phase in March 2019 and March 2020

Descriptive statistics of the concentration of air pollutant values for phase one and phase two are presented in Table 1 and Table 2 respectively.

Table 1. Descriptive statistics of air pollutants for the first phase

First phase period	01 March at 00:00 – 21 March at 00:00					
Year	2019	2020	2019	2020	2019	2020
Air Pollutant	PM_{10}		O_3		NO_2	
Mean	31,599	30,152	92,286	63,966	18,824	17,205
Standard Error	0,612	0,758	1,801	1,158	0,709	0,592
Median	29,281	28,744	89,626	68,461	14,314	12,962
Mode	29	23	106,124	91,137	13,073	3,935
Standard Deviation	13,7431	17,0130	40,428	25,998	15,917	13,286
Sample Variance	188,874	289,442	1634,429	675,904	253,353	176,527
Range	82,525	86,639	173,291	120,469	73,489	60,909
Minimum	0	0	4,844	5,340	0,282	0,263
Maximum	82,525	86,639	178,135	125,809	73,771	61,172
Sum	15925,858	15196,574	46512,202	32239,013	9487,321	8671,454
Count	504	504	504	504	504	504

Table 2. Descriptive statistics of air pollutants for the second phase

Second phase period	22 March at 00:00 – 31 March at 00:00					
Year	2019	2020	2019	2020	2019	2020
Air Pollutant	PM_{10}		O_3		NO_2	
Mean	36,519	57,116	104,330	68,046	18,079	7,820
Standard Error	1,170	4,369	2,697	1,053	1,358	0,438
Median	31,800	29,633	103,302	68,508	9,531	5,749
Mode	26	8	N/A	N/A	4,800	4,515
Standard Deviation	18,084	67,549	41,692	16,274	20,999	6,766
Sample Variance	327,036	4562,894	1738,187	264,851	440,954	45,785
Range	99,341	295,734	194,938	88,431	92,180	46,990
Minimum	13,506	3,083	4,628	27,277	0,018	1,134
Maximum	112,847	298,817	199,566	115,708	92,198	48,125
Sum	8728,038	13650,782	24934,951	16263,042	4320,788	1868,935
Count	239	239	239	239	239	239

Correlation coefficients were computed as the measure of the strength of linear association between each concentration of air pollutants PM_{10}, O_3 and NO_2 and each meteorological parameter: temperature, pressure, humidity, wind speed and wind direction for the first and the second phase in March 2019 and March 2020.
Coefficients of correlation for the first phase of March 2019 and March 2020 are shown in Table 3 and Table 4 respectively.

Table 3. Coefficients of correlation for the first phase in March 2019

2019 – the first phase	PM_{10}	O_3	NO_2
Temperature	-0,28547	0,72113	-0,12359
Pressure	0,26448	-0,31041	0,09124
Humidity	0,22804	-0,81242	0,22869
Wind speed	-0,27823	0,58961	-0,55696

Table 4. Coefficients of correlation for the first phase in March 2020

2020 – the first phase	PM_{10}	O_3	NO_2
Temperature	0,40572	0,56607	0,10839
Pressure	0,17819	0,01281	-0,04034
Humidity	-0,33461	-0,68282	0,06766
Wind speed	-0,16882	0,41430	-0,62981

From Table 3. it can be seen that PM_{10} is negatively correlated with temperature and wind speed, while PM_{10} is positively correlated with pressure and humidity. O_3 is positively correlated with temperature and wind speed, while O_3 is negatively correlated with pressure and humidity. NO_2 is negatively correlated with wind speed and temperature, while NO_2 is positively correlated with pressure and humidity.
From Table 4. it can be seen that PM_{10} is negatively correlated with humidity and wind speed, while PM_{10} is positively correlated with temperature and pressure. O_3 is negatively correlated with humidity, while O_3 is positively correlated with temperature, pressure and wind speed. NO_2 is negatively correlated with pressure and wind speed, while NO_2 is positively correlated with temperature and humidity.
Coefficients of correlation for the second phase of March 2019 and March 2020 are shown in Table 5 and Table 6 respectively.

Table 5. Coefficients of correlation for the second phase in March 2019

2019 – the second phase	PM_{10}	O_3	NO_2
Temperature	-0,14298	0,50153	-0,13487
Pressure	0,00244	-0,14888	-0,05620
Humidity	0,28450	-0,65782	0,23900
Wind speed	-0,27305	0,53053	-0,50734

Table 6. Coefficients of correlation for the second phase in March 2020

2020 – the second phase	PM_{10}	O_3	NO_2
Temperature	0,46940	0,35862	0,23090
Pressure	-0,53035	-0,17593	-0,20102
Humidity	-0,23056	-0,65354	-0,17395
Wind speed	-0,15095	0,40351	-0,35951

From Table 5. it can be seen that PM_{10} is negatively correlated with temperature and wind speed, while PM_{10} is positively correlated with pressure and humidity. O_3 is positively correlated with temperature and wind speed, while O_3 is negatively correlated with pressure and humidity. NO_2 is negatively correlated with temperature, pressure and wind speed, while NO_2 is positively correlated with humidity.

From Table 6. it can be seen that PM_{10} is negatively correlated with pressure, humidity and wind speed, while PM_{10} is positively correlated with temperature. O_3 is negatively correlated with pressure, humidity and wind direction, while O_3 is positively correlated with temperature and wind speed. NO_2 is negatively correlated with pressure, humidity and wind speed, while NO_2 is positively correlated with temperature and wind direction.
It can be seen that there are differences in certain coefficients of correlation between concentration of air pollutants and meteorological parameters not only in magnitude but in sign of coefficients of correlation as well.

3. Hypothesis testing and discussion of results

Hypothesis testing method was performed to estimate differences between two means for March 2019 and March 2020 for each air pollutant separately for time periods of both phases. Comparison of the values was done using hypothesis testing. Level of significance for this research is $\alpha = 0{,}05$ which is probability of committing Type I error. A Type I error occurs if the null hypothesis, H_0, is rejected when the null hypothesis is actually true and should not be rejected. After determining the level of significance, critical values that divide region of rejection and region of nonrejection of the null hypothesis were obtained. The rejection region of the null hypothesis is known since it is probability that the null hypothesis is rejected when it is true and should not be rejected. Thus, the confidence coefficient for this research is $(1 - \alpha) = 0{,}95$. Confidence coefficient is the probability that the null hypothesis is not rejected when it is true and should not be rejected. Also, observed level of significance $p -$ value was calculated for each air pollutant hypothesis testing. The $p -$ value represents the probability of obtaining a test statistic at least as extreme (equal or more extreme) than calculated test statistic assuming the null hypothesis is true. The null hypothesis is rejected if $p -$ value $< \alpha$, otherwise the null hypotheses is not rejected. For each air pollutant one-tailed test was performed.
The null and alternative hypotheses for PM_{10}, O_3 and NO_2 for the first phase are shown in Table 7.

Table 7. The null and alternative hypotheses for PM_{10}, O_3 and NO_2 for the first phase

Second phase period	01 March at 00:00 – 21 March at 23:00					
Air pollutant	PM_{10}		O_3		NO_2	
Year	2019	2020	2019	2020	2019	2020
Mean pollutant concentration	μ_1	μ_2	μ_1	μ_2	μ_1	μ_2
The null (H_0) and alternative (H_1) hypotheses	H_0: $\mu_1 - \mu_2 \leq 0$ H_1: $\mu_1 - \mu_2 > 0$		H_0: $\mu_1 - \mu_2 \leq 0$ H_1: $\mu_1 - \mu_2 > 0$		H_0: $\mu_1 - \mu_2 \leq 0$ H_1: $\mu_1 - \mu_2 > 0$	

Test statistic value, critical value as well as $p -$ values for the hypothesis testing for PM_{10} are $t_{stat} =$ 1,485, $t_{crit} =$ 1,646 and p – value = 0,068. Because t_{stat} =1,485 < t_{crit} = 1,646 and p – value = 0,068 > $\alpha = 0{,}05$ decision is "do not reject the null hypothesis". There is insufficient evidence to conclude that the mean PM_{10} value for the first phase in March 2019 is greater than the mean PM_{10} value for the first phase in March 2020.
Test statistic value, critical value as well as $p -$ value for the hypothesis testing for O_3 are $t_{stat} =$ 13,227; $t_{crit} =$ 1,646 and p – value = 0,000. Because t_{stat} =13,227 > t_{crit} = 1,647 and p – value = 0,000 < $\alpha = 0{,}05$ decision is to "reject the null hypothesis". There is statistical evidence to conclude that the mean O_3 value for the first phase in March 2019 is greater than the mean O_3 value for the first phase in March 2020.
Test statistic value, critical value as well as $p -$ value for the hypothesis testing for NO_2 are $t_{stat} =$ 1,752; $t_{crit} =$ 1,646 and p – value = 0,039. Because t_{stat} =1,752 > t_{crit} = 1,646 and p – value = 0,039 < $\alpha = 0{,}05$ decision is to "reject the null hypothesis". There is statistical evidence to conclude that the mean NO_2 value for the first phase in March 2019 is greater than the mean NO_2 value for the first phase in March 2020.
The null and alternative hypotheses for PM_{10}, O_3 and NO_2 for the second phase period are shown in Table 8.

Table 8. The null and alternative hypotheses for PM_{10}, O_3 and NO_2 for the second phase

Second phase period	22 March at 00:00 – 31 March at 23:00					
Air Pollutant	PM_{10}		O_3		NO_2	
Year	2019	2020	2019	2020	2019	2020
Mean pollutant concentration	μ_1	μ_2	μ_1	μ_2	μ_1	μ_2
The null (H_0) and alternative (H_1) hypotheses	H_0: $\mu_2 - \mu_1 \leq 0$ H_1: $\mu_2 - \mu_1 > 0$		H_0: $\mu_1 - \mu_2 \leq 0$ H_1: $\mu_1 - \mu_2 > 0$		H_0: $\mu_1 - \mu_2 \leq 0$ H_1: $\mu_1 - \mu_2 > 0$	

Test statistic value, critical value as well as $p -$ value for the hypothesis testing for PM_{10} are t_{stat} = 4,553; t_{crit} = 1,650 and p – value = 0,000. Because t_{stat} =4,553 > t_{crit} = 1,650 and p – value = 0,000 < α = 0,05 decision is to "reject the null hypothesis". There is statistical evidence to conclude that the mean PM_{10} value for the second phase in March 2020 is greater than the mean PM_{10} value for the second phase in March 2019. It can be seen from Fig. 4 that there is rise of PM_{10} value starting on 27 March 2020 at 03:00 am with the peak value of 298,8 $\mu g/m^3$ on 28 March 2020 at 01:00 am. This spike of PM_{10} ended on 31 March 2020 at 00:00 which influenced obtained results of this analysis.
Test statistic value, critical value as well as $p -$ value for the hypothesis testing for O_3 are t_{stat} = 12,533; t_{crit} = 1,650 and p – value = 0,000. Because t_{stat} =12,533 > t_{crit} = 1,650 and p – value = 0,000 < α = 0,05 decision is to "reject the null hypothesis". There is statistical evidence to conclude that the mean O_3 value for the second phase in March 2019 is greater than the mean O_3 value for the first phase in March 2020.
Test statistic value, critical value as well as $p -$ value for the hypothesis testing for NO_2 are t_{stat} = 7,188; t_{crit} = 1,650 and p – value = 0,000. Because t_{stat} =7,188 > t_{crit} = 1,650 and p – value = 0,000 < α = 0,05 decision is to "reject the null hypothesis". There is statistical evidence to conclude that the mean NO_2 value for the second phase in March 2019 is greater than the mean NO_2 value for the first phase in March 2020.

Table 9. The null and alternative hypotheses for PM_{10}, O_3 and NO_2 before and during lockdown in March 2020

Before Lockdown	01 March at 00:00 – 21 March at 23:00					
During Lockdown	22 March 2020 at 00:00 – 31 March 2020					
Air pollutant	PM_{10}		O_3		NO_2	
Lockdown	Before	During	Before	During	Before	During
Mean pollutant concentration	μ_1	μ_2	μ_1	μ_2	μ_1	μ_2
The null (H_0) and alternative (H_1) hypotheses	H_0: $\mu_2 - \mu_1 \leq 0$ H_1: $\mu_2 - \mu_1 > 0$		H_0: $\mu_2 - \mu_1 \leq 0$ H_1: $\mu_2 - \mu_1 > 0$		H_0: $\mu_1 - \mu_2 \leq 0$ H_1: $\mu_1 - \mu_2 > 0$	

Test statistic value, critical value as well as $p -$ value for the hypothesis testing for PM_{10} are t_{stat} = 6,080; t_{crit} = 1,650 and p – value = 0,000. Because t_{stat} =6,080 > t_{crit} = 1,650 and p – value = 0,000 < α = 0,05 decision is to "reject the null hypothesis". There is statistical evidence to conclude that the mean PM_{10} value during the lockdown period in March 2020 is greater than the mean PM_{10} value before lockdown in March 2020.
Test statistic value, critical value as well as $p -$ value for the hypothesis testing for O_3 are t_{stat} = 2,606; t_{crit} =1,647 and p – value = 0,004. Because t_{stat} =2,606 > t_{crit} = 1,647 and p – value = 0,004 < α = 0,05 decision is to "reject the null hypothesis". There is statistical evidence to conclude that the mean O_3 value during the lockdown period in March 2020 is greater than the mean O_3 value before lockdown in March 2020.

Test statistic value, critical value as well as $p-$value for the hypothesis testing for NO_2 are $t_{stat} = 12{,}750$; $t_{crit} = 1{,}647$ and p – value = 0,000. Because t_{stat} =12,750 > t_{crit} = 1,647 and p – value = 0,000 < $\alpha = 0{,}05$ decision is to "reject the null hypothesis". There is statistical evidence to conclude that the mean NO_2 value before lockdown in March 2020 is greater than the mean NO_2 value during the lockdown period in March 2020.

4. Conclusion

In this paper statistical hypothesis testing is performed to analyse whether there is change in air quality in Sarajevo during lockdown caused by outbreak of the novel coronavirus SARS-CoV-2. Mean values of air pollutants PM_{10}, O_3 and NO_2 are compared for the same periods of March 2019 and 2020 before and during lockdown as well as before and during lockdown period in March 2020. It is shown that before the lockdown measures there is insufficient evidence to conclude that the mean PM_{10} value in March 2019 is greater than the mean PM_{10} in March 2020.

There is statistical evidence to conclude that the mean O_3 and NO_2 values for the first phase in March 2019 are greater than the mean O_3 and NO_2 values for the first phase in March 2020, while there is insufficient evidence to conclude that the mean PM_{10} value for the first phase in March 2019 is greater than the mean PM_{10} value for the first phase in March 2020.

There is statistical evidence to conclude that the mean O_3 and NO_2 values for the second phase in March 2019 are greater than the mean O_3 and NO_2 values for the first phase in March 2020, while there is statistical evidence to conclude that the mean PM_{10} value for the second phase in March 2020 is greater than the mean PM_{10} value for the second phase in March 2019.

There is statistical evidence to conclude that the mean PM_{10} and O_3 values during the lockdown period in March 2020 are greater than the mean PM_{10} and O_3 values before lockdown in March 2020, while there is statistical evidence to conclude that the mean NO_2 value before lockdown in March 2020 is greater than the mean NO_2 value during the lockdown period in March 2020.

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