

Original Research Article**COVID-19 and Lahore: Unmasking the Pandemic's Effect on One of the Most Polluted Cities in the World****ABSTRACT**

Background: The COVID-19 pandemic has resulted in disruption to all spheres of life and its effects have been far reaching. One such effect is a decrease in air pollution levels across the globe. As a response to the spread of the disease, many governments have enforced lockdowns, which have limited movement and industrial output, and this in turn has resulted in air pollution levels plummeting. Since Lahore, Pakistan, is one of the most polluted cities in the world, analyzing the effects of COVID-19 mitigating measures within this city is of the utmost importance for future policy making with regards to air pollution.

Materials and Methods: The IQAir web and mobile application were used to acquire daily average PM_{2.5} values (in ug/m³) and USA AQI in Lahore from 1st March to 31st May, 2020, provided by the United States Consulate in Lahore. Additionally, data for the same period in 2019 was acquired from the Environment Protection Department of Pakistan. All the data was then further grouped into the period before COVID-19 (March-May 2019) and the period during COVID-19 related mitigating measures (March-May 2020). A paired t-test statistical analysis was then carried out between the two periods.

Results: From 2019 to 2020, there has been an increase of 275.0% in the number of days with "Moderate" PM_{2.5} levels (corresponding to PM_{2.5} levels between 12-35 ug/m³), an increase of 57.1% in the number of days with "Unhealthy for sensitive groups" PM_{2.5} levels (corresponding to PM_{2.5} levels of 35-55 ug/m³), a 73.1% decrease in the number of days with "Unhealthy" PM_{2.5} levels (corresponding to 55-150 ug/m³ PM_{2.5} levels) and a 100.0% decrease in the number of days with "Very unhealthy" PM_{2.5} levels (corresponding to 150-250 ug/m³ PM_{2.5} levels). Overall, there has been a decrease in the number of days with more severe and an increase in the number of days with less severe PM_{2.5} levels during COVID-19 related mitigating responses and this decrease is statistically significant.

Conclusions: COVID-19 mitigating measures have resulted in a significant drop in PM_{2.5} air pollution levels in Lahore. Since air pollution is a growing public health concern, the way forward is an analysis of the lockdown measures that were introduced as a result of COVID-19 and applying them permanently in a way that is publicly acceptable as well as environmentally friendly and economically **viable**.

KEYWORDS: Particulate matter, Air pollution, COVID-19, SARS-CoV-2, COVID-19 related air pollution, Urban pollution, PM_{2.5}, US **AQI**

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This study investigated the affect of COVID-19 related mitigating measures on the air pollution level in Lahore, Pakistan, which is one of the most polluted cities in the world. Results suggest that there has been a significant decrease in PM_{2.5} emissions as a result of these measures.

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INTRODUCTION

The Coronavirus disease of 2019 (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has disrupted life as we know it in all spheres of life. Governments have had to cope with the spread of the disease by introducing unprecedented levels of controls on public movement and industrial function by imposing lockdowns, sometimes even for a few months. This new form of measures aimed at curbing the spread of the disease have had a significant effect on many aspects of life such as more people working remotely, decrease in industrial output, decrease in the number of automobiles on the roads, the number of ships out at sea, the number of planes in the air, etc. As a consequence of these measures, worldwide levels of air pollution have gone down substantially. Cities like London (UK), Wuhan (China), Seoul (South Korea) and Milan (Italy), have had a decrease in air pollution levels by almost a third after lockdown measures were enforced [1]. Additionally, major European cities have reported a drop in air pollution levels by about 45% on average [2]. The decrease in air pollution levels has been dramatic in certain areas, such as in New Delhi (India), which is regarded as one of the most polluted cities in the world. In just one-week, fine particulate matter of diameter less than 2.5µm (PM_{2.5}) levels in New Delhi dropped from 91µg/m³ to 26µg/m³, a 71% drop [3]. Closer to home, a study conducted by the Sindh Environmental Protection Agency has found that air pollution levels in Karachi (Pakistan) have improved by 39% [4].

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These studies suggest that lockdown measures in response to COVID-19 have had a direct impact on decreasing air pollution levels, particularly PM_{2.5} levels. PM_{2.5} is regarded as one of the most dangerous pollutants since their small size makes it easy for them to be inhaled and to enter the bloodstream. Since air pollution causes approximately 29% of lung cancer deaths, 43% of chronic obstructive pulmonary disease deaths and 25% of ischemic heart disease deaths, it is of paramount importance to analyze and interpret the effects of lockdown measures on air pollution levels so that policies can then be implemented that allow for continued decrease in air pollution even after the pandemic is over [5].

Most of the studies conducted on a decrease in air pollution due to COVID-19 related lockdown measures have focused on capital cities around the world [5]. This study has focused on Lahore since it is an urban city with a population of 11 million and a decrease in human activity in such a huge urban populace is hypothesized to result in a decrease in air pollution levels. Additionally, Lahore has not only continuously been within the top 30 most polluted cities around the world but has also, on occasion, been the number one most polluted city globally [6, 7]. These reasons make it important to analyze how the air pollution levels in this city have been affected as a result of the COVID-19 induced lockdown measures. Air pollution within Lahore is mainly caused by a combination of vehicle and industrial emissions. Additionally, smoke from brick kilns, burning of crop residues and dust from construction sites adds to this pollution [8]. Since these causes mainly result in the formation of air pollution of the PM_{2.5} type [9], which is one of

the most dangerous types of air pollutants, this study has focused on how the PM_{2.5} levels have been affected before and during lockdown measures as a response to the spread of COVID-19.

MATERIALS AND METHODS

The IQAir web and mobile application were used to acquire average PM_{2.5} values (in ug/m³) and USA AQI (Air Quality Index) in Lahore from 1st March, 2020 to 31st May, 2020, on a daily basis. This data within the IQAir web and mobile applications was provided by the United States Consulate in Lahore, which carries out daily air quality monitoring in the city. Additionally, data for the same months in 2019 was acquired from the Environment Protection Department of Pakistan [10] and the US Consulate in Lahore [11].

The data acquired was sorted chronologically and then was further grouped into the period before isolation measures, lockdown and before a decrease in human activity due to COVID-19 (March-May 2019) and during isolation measures, lockdown and after a decrease in human activity due to COVID-19 (March-May 2020). Table 1 shows the data in a tabular form, together with the USA AQI color coding system based on the PM_{2.5} levels [12]. After the data was sorted, two-tailed paired t test and visual analysis was carried out using GraphPad Prism 8.4.3.

For the purposes of this study, a significant result was concluded if the corresponding p-value was calculated to be less than 5%. Furthermore, within this study, wherever “2019” is mentioned, it is to be considered as analogous to the period March 2019-May 2019 or the period before responses, such as lockdown, to COVID-19 were enforced. Additionally, wherever “2020” is mentioned, it should be considered analogous to the period March 2020-May 2020 or the period during which responses, such as lockdown, to COVID-19 were enforced. Furthermore, data for the same months in 2018 were also used from the Environment Protection Department of Pakistan [13] to confirm the results obtained.

Based on what has been seen in other cities and previous studies, the following hypothesis were used for the purposes of this study:

Null hypothesis (H₀): There is no statistically significant difference in the mean PM_{2.5} levels in Lahore before (M_B) and during (M_D) lockdown measures in response to COVID-19.

$$H_0: M_B = M_D$$

Alternative hypothesis (H_A): There is a statistically significant difference in the mean PM_{2.5} levels in Lahore before (M_B) and during (M_D) the lockdown measures in response to COVID-19.

$$H_A: M_B \neq M_D$$

RESULTS

Daily average values of PM_{2.5} and US AQI show a visual difference over the period March-May between the two different years (Figure 1a and Figure 1d). Additionally, mean yearly (Figure 1b and Figure 1e) and mean monthly (Figure 1c and Figure 1f) values of PM_{2.5} and US AQI show a decreasing trend per year and within the same month of different years.

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A decrease is also seen with regards to the number of days with more severe US AQI ratings (Figure 2a and Figure 2b). From 2019 to 2020, there has been an increase of 275.0% in the number of days with “Moderate” PM_{2.5} levels (corresponding to PM_{2.5} levels between 12-35 ug/m³ [14]), an increase of 57.1% in the number of days with “Unhealthy for sensitive groups” PM_{2.5} levels (corresponding to PM_{2.5} levels of 35-55 ug/m³ [13]), a 73.1% decrease in the number of days with “Unhealthy” PM_{2.5} levels (corresponding to 55-150 ug/m³ PM_{2.5} levels [14]) and a 100.0% decrease in the number of days with “Very unhealthy” PM_{2.5} levels (corresponding to 150-250 ug/m³ PM_{2.5} levels [14]).

There is a stark difference between the mean PM_{2.5} levels before and during COVID-19 curbing responses (Table 2) and these differences are statistically significant (Table 3). The main results between 2019 (March-May) and 2020 (March-May) show a significant decrease in PM_{2.5} levels and this significant decrease also holds between each corresponding month of the different years (for example, there is a significant decrease in PM_{2.5} levels when comparing March 2019 and March 2020). To confirm that these results were due to measures against the spread of COVID-19, data for 2018 (March-May) was also analyzed. The results indicate (Table 3), as expected, that there is no statistical significance in the PM_{2.5} levels during the similar period in 2018 and 2019; statistical significance only arises for these values between 2018 and 2020 and between 2019 and 2020.

DISCUSSION

It was logical to use and compare data of similar months (March-May) for each year as opposed to using data from months directly preceding the advent of COVID-19 (October-December). This was done due to two main reasons. Firstly, air pollution in Lahore is much worse and the PM_{2.5} levels are much higher in the winter months than in any other period of the year, mainly because farmers in Punjab tend to burn crop remnants, producing smoke that adds to Lahore’s smog issue [15, 16]. The smog and high PM_{2.5} levels tend to linger due to the weather changes and the cold environment, which results in these pollutants remaining trapped in the troposphere. The high levels of air pollution in Lahore in the winter can be gauged by the fact that in November 2019, Lahore regularly came second to New Delhi as the most polluted city, and even topped the list for a few weeks [8]. Therefore, data from the winter months was not used since any differences in data could not have been attributed majorly to COVID-19 related mitigating factors since a higher PM_{2.5} average in the winter months would have been a good alternative explanation as to why there was a difference in air pollution before and during COVID-19 related mitigating measures. The second logic follows from the first that similar months were compared between the different years to minimize the effect of any other variables which might have led to greater differences if different months were compared. In other words, using the same months for comparison meant that this was kept as a constant between the different years under study.

The results provide strong evidence to reject the null hypothesis and to conclude that there is a significant decrease in the PM_{2.5} levels as a result of COVID-19 related mitigating measures. Since the major difference between the two periods under study (2019 and 2020) is the lockdown and other measures to curb the spread of COVID-19, this significant decrease can be attributed to

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these measures and any confounding or lurking variables have little to negligible effect, if any, on this decrease. Additionally, this result is in line with other studies which have reported a decrease in air pollution levels in different cities around the world [5].

A significant decrease in air pollution levels across the world because of COVID-19 related mitigating responses have given rise to ideas about introducing some of these measures in a post-pandemic world. These ideas, and their implementation, are ever more important when considering how some regions, after easing these measures and lockdowns, have seen a surge in air pollution to levels before these measures were enforced. China, one of the countries with the highest PM_{2.5} emissions, which saw a decrease of about 34% in these emissions, has recently seen an increase in air pollution to levels before the pandemic after easing of lockdowns [17]. Since air pollution has been associated with a myriad of different health concerns and is a growing public health issue, an in-depth analysis is necessary with regards to COVID-19 related mitigating factors and how they can be implemented even after the pandemic subsides. Pakistan, which was the fifth most polluted country in the world in 2016, has had an increase of 54% since 1998 in its PM_{2.5} levels. This increase has been associated with the average Pakistani losing about 2.7 years of life expectancy when compared to what the life expectancy would have been if the World Health Organization's (WHO) guideline of keeping emissions at a maximum of 10ug/m³ were met. This health concern is most alarming and detrimental in Lahore, where residents on average could lose about 5.3 years off their lives due to these emissions [18].

Air pollution, and its associated health concerns, are a commonality among low, middle and high-income countries, with the heaviest burden being suffered by the low-income countries. Air pollution associated deaths amount to about 4.2 million annually [19] and are mostly caused by exposure to PM_{2.5} pollutants, which exacerbate cardiovascular and respiratory conditions and can even result in cancers. As of 2016, about 91% of the world's population lives in places where the WHO guidelines are not met. By minimizing air pollutant emissions, the burden of disease from stroke, heart disease, lung cancer and respiratory diseases can be reduced. It is estimated that by adhering to WHO air quality guidelines on PM_{2.5} thresholds, air pollution related deaths can be decreased by about 15% [19].

Given the damage the PM_{2.5} pollutants can incur, and the realization that COVID-19 related mitigating factors have resulted in a decrease in these emissions, it is imperative that these measures are further developed in a socially acceptable way. The way forward is for the government to firstly conduct a study on how lockdown measures and decrease of automotive and industrial functioning can be applied to society in a way that is environmentally friendly and economically feasible and then allocate funds for this process, especially monitoring progress so that areas transgressing guidelines can be kept in check. Considering the bleak outlook of how residents of Lahore can lose about 5.3 years from their lives due to high PM_{2.5} levels, the need of the hour is establishing a stringent action plan to prevent adverse outcomes on public health and to reduce the economic burden on the country [20]. Other measures to improve the situation is by raising awareness. The public needs to be aware of the possible health issues associated with high air pollution levels and how COVID-19 related mitigating measures have had a positive impact on our environment. Public servicemessages on television, radio, and the internet, along

with the distribution of educational pamphlets and brochures can be a few of the effective steps for raising awareness [20].

CONCLUSIONS

Lockdown measures as a result of the spread of COVID-19 have resulted in a significant drop in PM_{2.5} air pollution levels in Lahore and studies have also shown this to be true in other regions around the world. The situation is more alarming in Lahore, which has one of the highest pollution levels in the world and its residents can lose about 5.3 years from their lives due to air pollution. Since climate change and its effects are becoming ever more apparent and disastrous, there is a dire need to give more attention to mitigating the effects of human activities which are contributing to this phenomenon. One such way that this can be achieved is an analysis of the lockdown measures that were introduced as a result of COVID-19 and applying them permanently in a way that is publicly acceptable as well as environmentally friendly and economically viable.

FIGURE AND TABLE LEGENDS

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Table 1: Average Daily PM_{2.5} Values (ug/m³) and US AQI for Lahore (March 2019-May 2019 and March 2020-May 2020)

Date	PM _{2.5} (ug/m ³)	US AQI	US AQI Rating and Color Code
01-Mar-20	89.4	169.0	Unhealthy
02-Mar-20	75.5	161.0	Unhealthy
03-Mar-20	53.3	145.0	Unhealthy for Sensitive Groups
04-Mar-20	56.0	151.0	Unhealthy
05-Mar-20	29.0	87.0	Moderate
06-Mar-20	22.0	72.0	Moderate
07-Mar-20	33.8	97.0	Moderate
08-Mar-20	45.7	126.0	Unhealthy for Sensitive Groups
09-Mar-20	34.1	97.0	Moderate
10-Mar-20	57.3	152.0	Unhealthy

11-Mar-20	39.2	110.0	Unhealthy for Sensitive Groups
12-Mar-20	17.4	62.0	Moderate
13-Mar-20	23.7	75.0	Moderate
14-Mar-20	43.6	121.0	Unhealthy for Sensitive Groups
15-Mar-20	65.3	156.0	Unhealthy
16-Mar-20	57.2	152.0	Unhealthy
17-Mar-20	70.3	159.0	Unhealthy
18-Mar-20	72.2	160.0	Unhealthy
19-Mar-20	87.6	168.0	Unhealthy
20-Mar-20	70.8	159.0	Unhealthy
21-Mar-20	49.4	135.0	Unhealthy for Sensitive Groups
22-Mar-20	49.6	136.0	Unhealthy for Sensitive Groups
23-Mar-20	50.5	138.0	Unhealthy for Sensitive Groups
24-Mar-20	34.8	99.0	Moderate
25-Mar-20	26.2	81.0	Moderate
26-Mar-20	24.3	77.0	Moderate
27-Mar-20	21.2	70.0	Moderate
28-Mar-20	24.9	78.0	Moderate
29-Mar-20	32.7	94.0	Moderate
30-Mar-20	28.9	86.0	Moderate
31-Mar-20	28.7	86.0	Moderate
01-Apr-20	18.2	64.0	Moderate
02-Apr-20	16.5	60.0	Moderate

03-Apr-20	26.7	82.0	Moderate
04-Apr-20	40.0	112.0	Unhealthy for Sensitive Groups
05-Apr-20	34.9	99.0	Moderate
06-Apr-20	16.0	59.0	Moderate
07-Apr-20	16.2	60.0	Moderate
08-Apr-20	26.4	81.0	Moderate
09-Apr-20	42.9	119.0	Unhealthy for Sensitive Groups
10-Apr-20	19.5	66.0	Moderate
11-Apr-20	27.2	83.0	Moderate
12-Apr-20	36.0	102.0	Unhealthy for Sensitive Groups
13-Apr-20	59.9	153.0	Unhealthy
14-Apr-20	43.0	119.0	Unhealthy for Sensitive Groups
15-Apr-20	40.8	114.0	Unhealthy for Sensitive Groups
16-Apr-20	32.6	94.0	Moderate
17-Apr-20	19.7	67.0	Moderate
18-Apr-20	17.1	61.0	Moderate
19-Apr-20	24.7	77.0	Moderate
20-Apr-20	24.8	78.0	Moderate
21-Apr-20	45.1	125.0	Unhealthy for Sensitive Groups
22-Apr-20	42.4	118.0	Unhealthy for Sensitive Groups
23-Apr-20	43.4	120.0	Unhealthy for Sensitive Groups
24-Apr-20	41.6	116.0	Unhealthy for Sensitive Groups
25-Apr-20	44.5	123.0	Unhealthy for Sensitive Groups

26-Apr-20	34.5	98.0	Moderate
27-Apr-20	17.0	61.0	Moderate
28-Apr-20	35.1	99.0	Moderate
29-Apr-20	39.8	112.0	Unhealthy for Sensitive Groups
30-Apr-20	38.8	109.0	Unhealthy for Sensitive Groups
01-May-20	57.6	152.0	Unhealthy
02-May-20	48.0	132.0	Unhealthy for Sensitive Groups
03-May-20	28.9	86.0	Moderate
04-May-20	35.3	100.0	Moderate
05-May-20	40.7	114.0	Unhealthy for Sensitive Groups
06-May-20	33.5	96.0	Moderate
07-May-20	40.0	112.0	Unhealthy for Sensitive Groups
08-May-20	49.7	136.0	Unhealthy for Sensitive Groups
09-May-20	43.7	121.0	Unhealthy for Sensitive Groups
10-May-20	35.8	102.0	Unhealthy for Sensitive Groups
11-May-20	29.1	87.0	Moderate
12-May-20	45.8	126.0	Unhealthy for Sensitive Groups
13-May-20	35.2	99.0	Moderate
14-May-20	33.5	96.0	Moderate
15-May-20	44.9	124.0	Unhealthy for Sensitive Groups
16-May-20	55.6	151.0	Unhealthy
17-May-20	47.4	130.0	Unhealthy for Sensitive Groups
18-May-20	54.3	147.0	Unhealthy for Sensitive Groups

19-May-20	40.6	113.0	Unhealthy for Sensitive Groups
20-May-20	33.2	95.0	Moderate
21-May-20	37.1	105.0	Unhealthy for Sensitive Groups
22-May-20	65.1	156.0	Unhealthy
23-May-20	33.8	96.0	Moderate
24-May-20	28.8	86.0	Moderate
25-May-20	41.8	116.0	Unhealthy for Sensitive Groups
26-May-20	37.3	105.0	Unhealthy for Sensitive Groups
27-May-20	28.7	86.0	Moderate
28-May-20	22.6	73.0	Moderate
29-May-20	22.9	74.0	Moderate
30-May-20	25.9	80.0	Moderate
31-May-20	32.0	93.0	Moderate

Table 2: Yearly (March-May) descriptive statistics of PM_{2.5} levels

Period	Statistic	PM _{2.5} (ug/m ³)	US AQI Rating
March-May 2018	Mean ± Standard deviation	83.24 ± 53.87	Unhealthy
	Minimum	18.00	Moderate
	Maximum	218.00	Very Unhealthy
March-May 2019	Mean ± Standard deviation	78.00 ± 40.79	Unhealthy
	Minimum	18.80	Moderate
	Maximum	212.30	Very Unhealthy
March-May 2020	Mean ± Standard deviation	39.01 ± 15.68	Unhealthy for Sensitive Groups
	Minimum	16.00	Moderate
	Maximum	89.40	Unhealthy

Table 3: Statistical analysis results (two tailed paired t-test, p < 0.05 level of significance)

Variables	p-value	p-value Summary
2018 Vs. 2019	0.4527	Not significant
2018 Vs. 2020	< 0.0001	Significant
2019 Vs. 2020	< 0.0001	Significant

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable

CONSENT FOR PUBLICATION

Not applicable

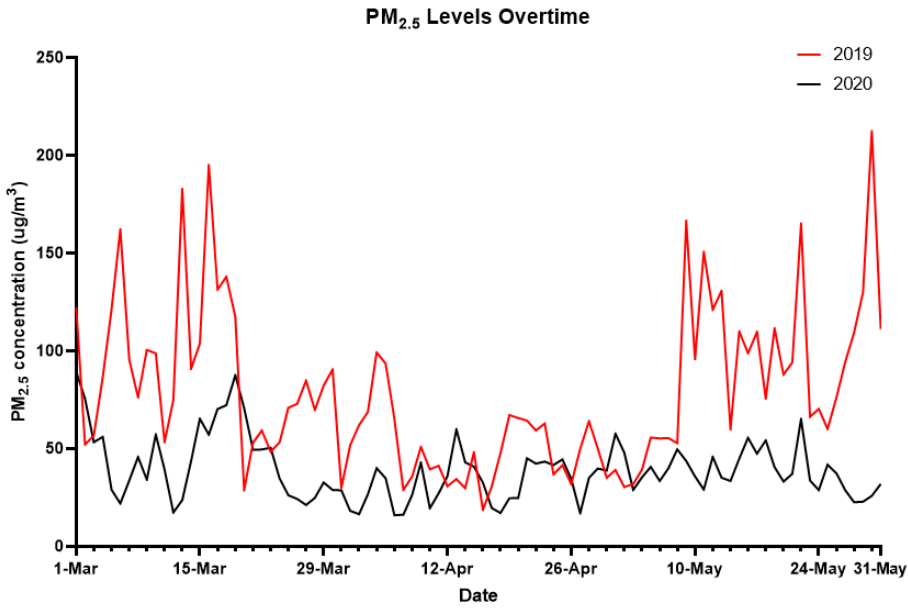
AVAILABILITY OF DATA AND MATERIALS

The datasets generated and/or analyzed during the current study are available in the IQAir repository (<https://www.iqair.com/us/pakistan/punjab/lahore>) and the Environment Protection Department of Pakistan repository (https://epd.punjab.gov.pk/air_quality).

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21.

Figure 1a: Daily mean PM_{2.5} concentration (ug/m³) from March-May 2019 and March-May 2020

Mean PM_{2.5} Concentration per Year

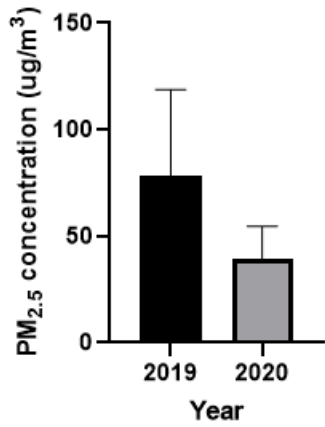


Figure 1b: Mean PM_{2.5} concentration (ug/m³) per year.

Mean PM_{2.5} Concentration per Month and Year

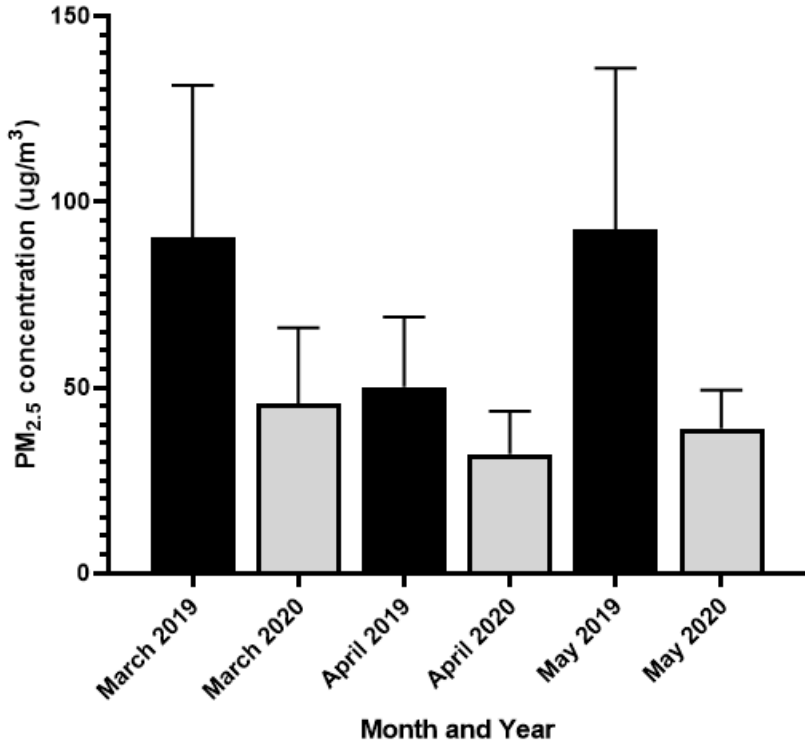


Figure 1c: Mean PM_{2.5} concentration (ug/m³) per year and month.

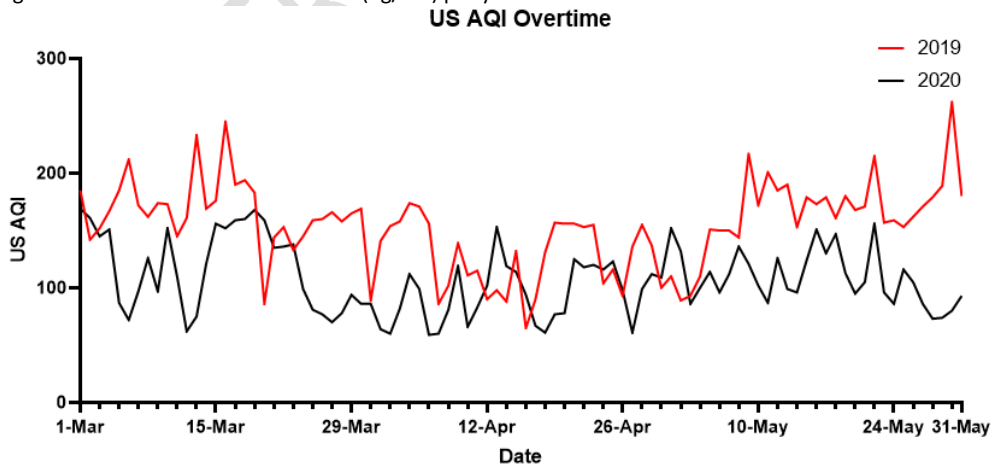


Figure 1d: Daily mean US AQI from March 2019-May 2019 and March 2020-May 2020

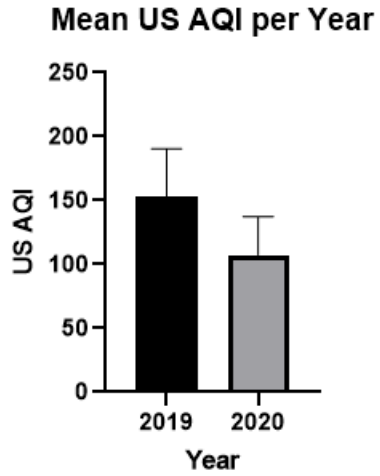


Figure 1e: Mean US AQI per year.

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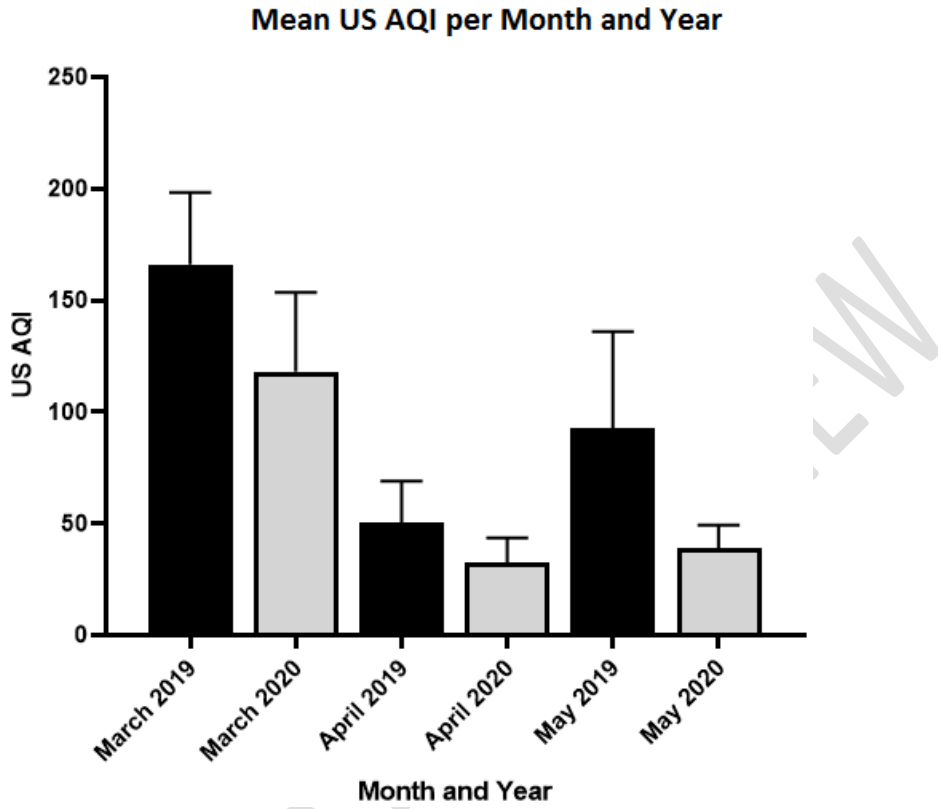


Figure 1f: Mean US AQI per year and month.

Comment [GdG9]: The authors must improve figure - 01 so that the variation bar can be seen for more and less in the graph, because the bars are found buried in the figure 01.

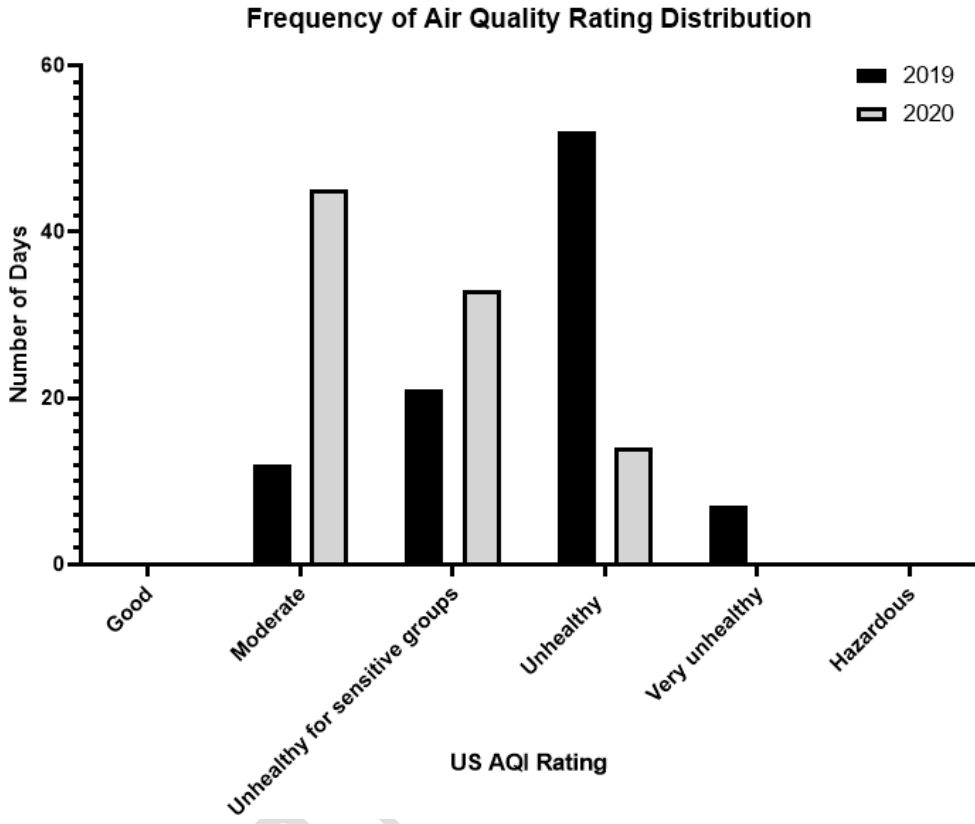


Figure 2a: Frequency of US AQI rating per year

UNDER

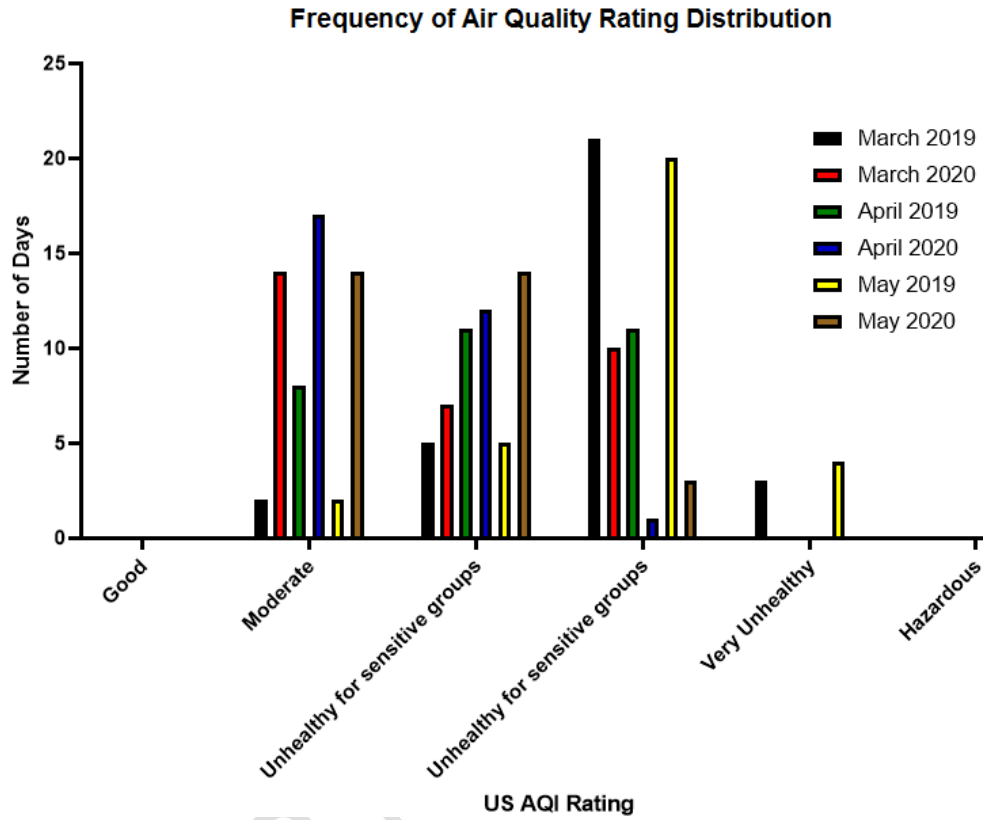


Figure 2b: Frequency of US AQI rating per year and month.

UNDER