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# COVID-19 and Lahore: Unmasking the Pandemic's Effect on One of the Most Polluted Cities in the World

**Hannan Latif [a*]**

[a] *University of Illinois at Chicago, United States of America.*

***Author's contribution***

*The sole author designed, analyzed, interpreted and prepared the manuscript.*

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## ABSTRACT

**Background:** The COVID-19 pandemic has had profound global impacts, including a noteworthy reduction in air pollution levels due to lockdown measures imposed by many governments. This study focuses on Lahore, Pakistan, a city notorious for its severe air pollution, to assess the effects of COVID-19 mitigation efforts on air quality, with implications for future policymaking.
**Methods:** Data on daily average $PM_{2.5}$ values (in ug/m3) and the USA Air Quality Index (AQI) in Lahore were obtained from March 1st to May 31st, 2020, courtesy of the United States Consulate in Lahore. Comparative data for the same period in 2019 was collected from the Environment Protection Department of Pakistan. The data was categorized into two periods: pre-COVID-19 (March-May 2019) and during COVID-19 mitigation measures (March-May 2020). Statistical analysis involved a paired t-test comparing these two periods.
**Results:** The results demonstrate substantial changes in air quality. Between 2019 and 2020, there was a 275.0% increase in the number of days with "Moderate" $PM_{2.5}$ levels (12-35 ug/m3), a 57.1% increase in the number of days with "Unhealthy for sensitive groups" $PM_{2.5}$ levels (35-55 ug/m3), a 73.1% decrease in the number of days with "Unhealthy" $PM_{2.5}$ levels (55-150 ug/m3), and a 100.0% decrease in the number of days with "Very unhealthy" $PM_{2.5}$ levels (150-250 ug/m3). Overall, a

**Corresponding author: E-mail: hlatif3@uic.edu;*

statistically significant reduction in more severe $PM_{2.5}$ pollution days and an increase in less severe pollution days were observed during COVID-19 mitigation measures.
**Conclusion:** In conclusion, COVID-19 mitigation efforts have led to a significant decline in $PM_{2.5}$ air pollution levels in Lahore. Given the growing concerns about air quality's impact on public health, it is imperative to consider incorporating some of these lockdown measures into permanent policies that are socially acceptable, environmentally sustainable, and economically viable. This study underscores the potential for long-term improvements in air quality and public health through targeted policy actions.

*Keywords: Particulate matter; air pollution; COVID-19; SARS-CoV-2; COVID-19 related air pollution; urban pollution; $PM_{2.5}$; US AQI.*

## 1. 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 2.5um ($PM_{2.5}$) levels in New Delhi dropped from 91ug/m$^3$ to 26ug/m$^3$, 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].

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.

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 ($H_0$): 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.

$H_A$: $M_B \neq M_D$

## 2. MATERIALS AND METHODS

The IQAir web and mobile application were used to acquire average $PM_{2.5}$ values (in $ug/m^3$) and USA AQI (Air Quality Index) in Lahore from 1st March, 2020 to 31st May, 2020, on a daily basis. The IQAir web and mobile application reports daily average values of $PM_{2.5}$ (in $ug/m^3$), which were noted for the duration of the study period. 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]. The application of a z-test using kurtosis and skewness was used to determine normality of the data. After the data was sorted, two-tailed paired t test and visual analysis was carried out using GraphPad Prism 8.4.3.

**Table 1. Average Daily $PM_{2.5}$ Values (ug/m3) and US AQI [22] for Lahore (March 2019-May 2019 and March 2020-May 2020)**

| Date | PM2.5 (ug/m^3) | US AQI | US AQI Rating and Color Code |
|---|---|---|---|
| 01-Mar-19 | 122.3 | 185.0 | Unhealthy |
| 02-Mar-19 | 52.1 | 142.0 | Unhealthy for Sensitive Groups |
| 03-Mar-19 | 56.7 | 152.0 | Unhealthy |
| 04-Mar-19 | 86.6 | 167.0 | Unhealthy |
| 05-Mar-19 | 121.2 | 185.0 | Unhealthy |
| 06-Mar-19 | 162.1 | 212.0 | Very Unhealthy |
| 07-Mar-19 | 95.4 | 172.0 | Unhealthy |
| 08-Mar-19 | 76.3 | 162.0 | Unhealthy |
| 09-Mar-19 | 100.5 | 174.0 | Unhealthy |
| 10-Mar-19 | 98.7 | 173.0 | Unhealthy |
| 11-Mar-19 | 53.3 | 145.0 | Unhealthy for Sensitive Groups |
| 12-Mar-19 | 74.8 | 161.0 | Unhealthy |
| 13-Mar-19 | 182.7 | 233.0 | Very Unhealthy |
| 14-Mar-19 | 90.9 | 169.0 | Unhealthy |
| 15-Mar-19 | 103.8 | 176.0 | Unhealthy |
| 16-Mar-19 | 195.0 | 245.0 | Very Unhealthy |
| 17-Mar-19 | 131.3 | 190.0 | Unhealthy |
| 18-Mar-19 | 138.0 | 194.0 | Unhealthy |
| 19-Mar-19 | 117.4 | 183.0 | Unhealthy |
| 20-Mar-19 | 28.8 | 86.0 | Moderate |
| 21-Mar-19 | 53.0 | 144.0 | Unhealthy for Sensitive Groups |
| 22-Mar-19 | 59.3 | 153.0 | Unhealthy |
| 23-Mar-19 | 48.5 | 133.0 | Unhealthy for Sensitive Groups |
| 24-Mar-19 | 53.2 | 145.0 | Unhealthy for Sensitive Groups |
| 25-Mar-19 | 70.9 | 159.0 | Unhealthy |
| 26-Mar-19 | 72.9 | 160.0 | Unhealthy |
| 27-Mar-19 | 84.9 | 166.0 | Unhealthy |
| 28-Mar-19 | 69.8 | 158.0 | Unhealthy |
| 29-Mar-19 | 82.3 | 165.0 | Unhealthy |

| Date | PM2.5 (ug/m^3) | US AQI | US AQI Rating and Color Code |
|---|---|---|---|
| 30-Mar-19 | 90.5 | 169.0 | Unhealthy |
| 31-Mar-19 | 30.1 | 69.0 | Moderate |
| 01-Apr-19 | 51.7 | 141.0 | Unhealthy for Sensitive Groups |
| 02-Apr-19 | 62.1 | 154.0 | Unhealthy |
| 03-Apr-19 | 68.8 | 158.0 | Unhealthy |
| 04-Apr-19 | 99.2 | 174.0 | Unhealthy |
| 05-Apr-19 | 93.5 | 171.0 | Unhealthy |
| 06-Apr-19 | 65.2 | 156.0 | Unhealthy |
| 07-Apr-19 | 28.9 | 86.0 | Moderate |
| 08-Apr-19 | 35.8 | 102.0 | Unhealthy for Sensitive Groups |
| 09-Apr-19 | 50.9 | 139.0 | Unhealthy for Sensitive Groups |
| 10-Apr-19 | 39.5 | 111.0 | Unhealthy for Sensitive Groups |
| 11-Apr-19 | 41.2 | 115.0 | Unhealthy for Sensitive Groups |
| 12-Apr-19 | 30.8 | 90.0 | Moderate |
| 13-Apr-19 | 34.5 | 98.0 | Moderate |
| 14-Apr-19 | 29.7 | 88.0 | Moderate |
| 15-Apr-19 | 48.2 | 132.0 | Unhealthy for Sensitive Groups |
| 16-Apr-19 | 18.8 | 65.0 | Moderate |
| 17-Apr-19 | 30.6 | 90.0 | Moderate |
| 18-Apr-19 | 47.6 | 131.0 | Unhealthy for Sensitive Groups |
| 19-Apr-19 | 67.2 | 157.0 | Unhealthy |
| 20-Apr-19 | 65.7 | 156.0 | Unhealthy |
| 21-Apr-19 | 64.4 | 156.0 | Unhealthy |
| 22-Apr-19 | 59.3 | 153.0 | Unhealthy |
| 23-Apr-19 | 62.9 | 155.0 | Unhealthy |
| 24-Apr-19 | 36.8 | 104.0 | Unhealthy for Sensitive Groups |
| 25-Apr-19 | 41.5 | 116.0 | Unhealthy for Sensitive Groups |
| 26-Apr-19 | 31.9 | 93.0 | Moderate |
| 27-Apr-19 | 49.9 | 136.0 | Unhealthy for Sensitive Groups |
| 28-Apr-19 | 64.1 | 153.0 | Unhealthy |
| 29-Apr-19 | 50.1 | 137.0 | Unhealthy for Sensitive Groups |
| 30-Apr-19 | 35.2 | 100.0 | Moderate |
| 01-May-19 | 39.1 | 110.0 | Unhealthy for Sensitive Groups |
| 02-May-19 | 30.4 | 89.0 | Moderate |
| 03-May-19 | 31.9 | 93.0 | Moderate |
| 04-May-19 | 39.3 | 110.0 | Unhealthy for Sensitive Groups |
| 05-May-19 | 55.7 | 151.0 | Unhealthy |
| 06-May-19 | 55.3 | 150.0 | Unhealthy for Sensitive Groups |
| 07-May-19 | 55.4 | 150.0 | Unhealthy for Sensitive Groups |
| 08-May-19 | 52.9 | 144.0 | Unhealthy for Sensitive Groups |
| 09-May-19 | 166.4 | 217.0 | Very Unhealthy |
| 10-May-19 | 95.8 | 172.0 | Unhealthy |
| 11-May-19 | 150.6 | 201.0 | Very Unhealthy |
| 12-May-19 | 121.0 | 185.0 | Unhealthy |
| 13-May-19 | 130.7 | 190.0 | Unhealthy |
| 14-May-19 | 60.0 | 153.0 | Unhealthy |
| 15-May-19 | 110.0 | 179.0 | Unhealthy |
| 16-May-19 | 98.8 | 173.0 | Unhealthy |
| 17-May-19 | 109.7 | 179.0 | Unhealthy |
| 18-May-19 | 75.6 | 161.0 | Unhealthy |
| 19-May-19 | 111.5 | 180.0 | Unhealthy |
| 20-May-19 | 87.9 | 168.0 | Unhealthy |
| 21-May-19 | 94.1 | 171.0 | Unhealthy |
| 22-May-19 | 165.0 | 215.0 | Very Unhealthy |
| 23-May-19 | 66.2 | 157.0 | Unhealthy |
| 24-May-19 | 70.4 | 159.0 | Unhealthy |

| Date | PM2.5 (ug/m^3) | US AQI | US AQI Rating and Color Code |
|---|---|---|---|
| 25-May-19 | 60.1 | 153.0 | Unhealthy |
| 26-May-19 | 76.3 | 162.0 | Unhealthy |
| 27-May-19 | 94.4 | 171.0 | Unhealthy |
| 28-May-19 | 109.3 | 179.0 | Unhealthy |
| 29-May-19 | 129.9 | 189.0 | Unhealthy |
| 30-May-19 | 212.3 | 262.0 | Very Unhealthy |
| 31-May-19 | 111.1 | 180.0 | Unhealthy |
| 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 |

| Date | PM2.5 (ug/m^3) | US AQI | US AQI Rating and Color Code |
|---|---|---|---|
| 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 |

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.

## 3. 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 (Fig. 1a and Fig. 1d). Additionally, mean yearly (Fig. 1b and Fig. 1e) and mean monthly (Fig. 1c and Fig. 1f) values of $PM_{2.5}$ and US AQI show a decreasing trend per year and within the same month of different years. The data obtained was determined to be normally distributed (z = 1.63) as per the guidelines suggested by Mishra et al (2019) [14].

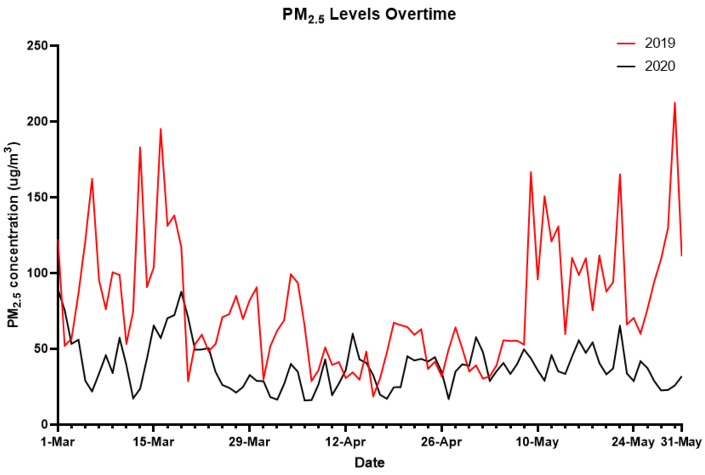


**Fig. 1a. Daily mean PM2.5 concentration (ug/m3) from March-May 2019 and March-May 2020**

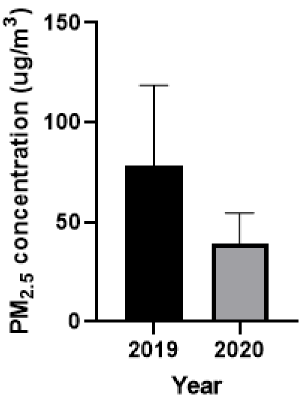


**Fig. 1b. Mean PM2.5 concentration (ug/m3) per year**

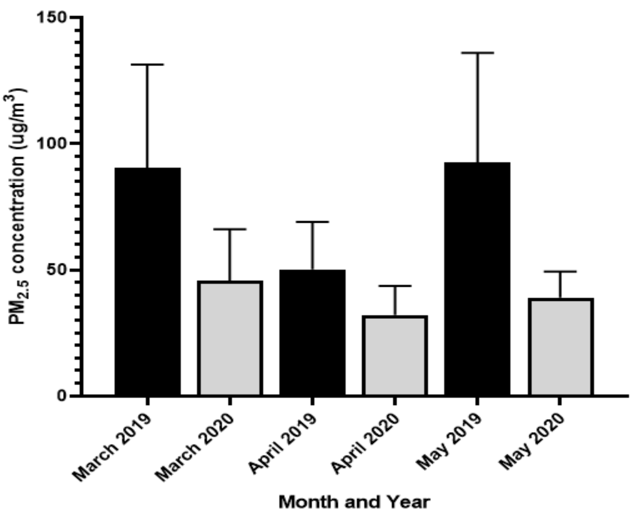


**Fig. 1c. Mean PM2.5 concentration (ug/m3) per year and month**

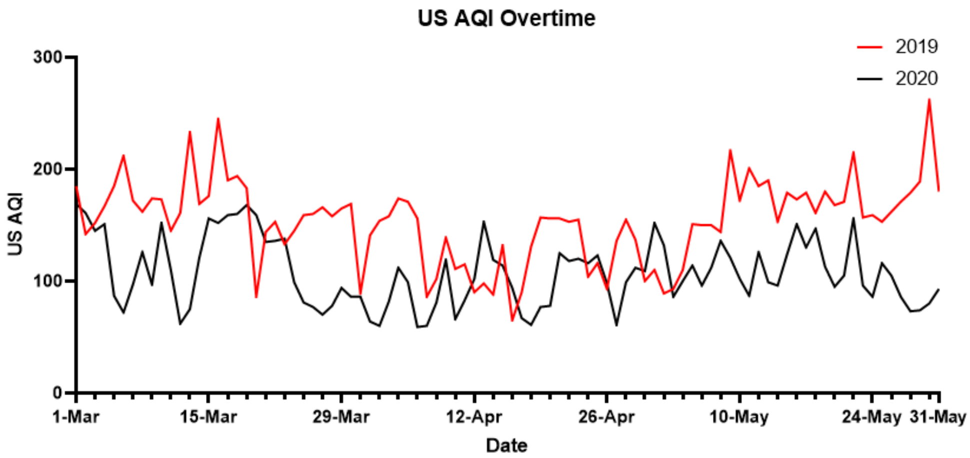


**Fig. 1d. Daily mean US AQI from March 2019-May 2019 and March 2020-May 2020**

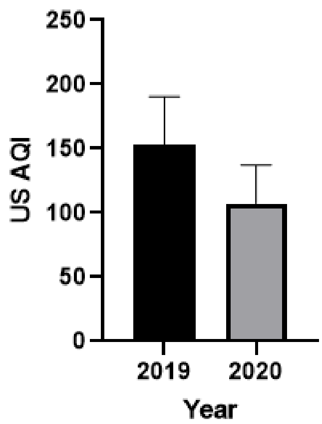


**Fig. 1e. Mean US AQI per year**

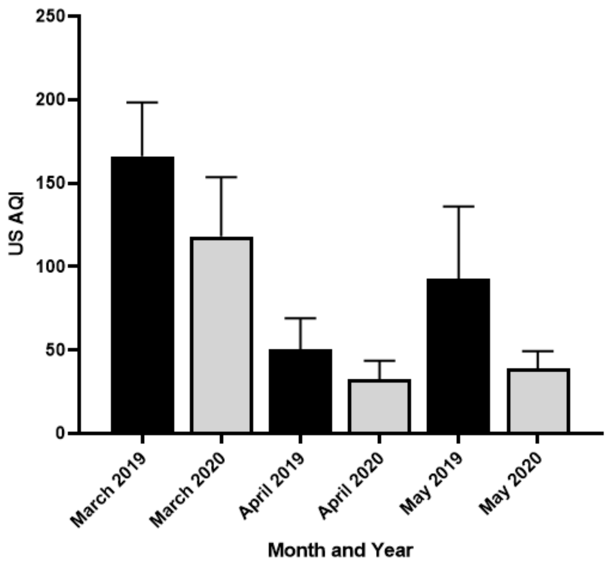


**Fig. 1f. Mean US AQI per year and month**

A decrease is also seen with regards to the number of days with more severe US AQI ratings (Fig. 2a and Fig. 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/$m^3$ [15], 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/$m^3$ [13], a 73.1% decrease in the number of days with "Unhealthy" $PM_{2.5}$ levels (corresponding to 55-150 ug/$m^3$ $PM_{2.5}$ levels [15) and a 100.0% decrease in the number of days with "Very unhealthy" $PM_{2.5}$ levels (corresponding to 150-250 ug/$m^3$ $PM_{2.5}$ levels [15].

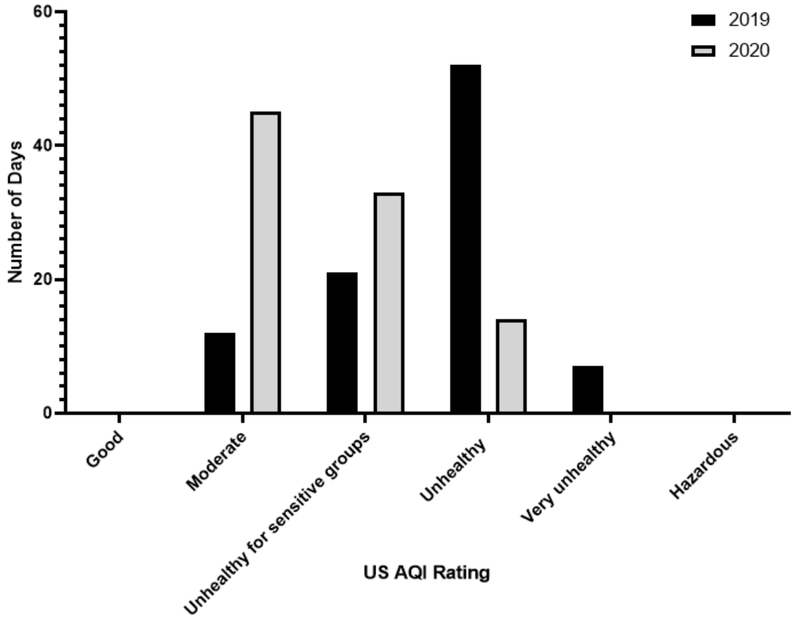


**Fig. 2a. Frequency of US AQI rating per year**

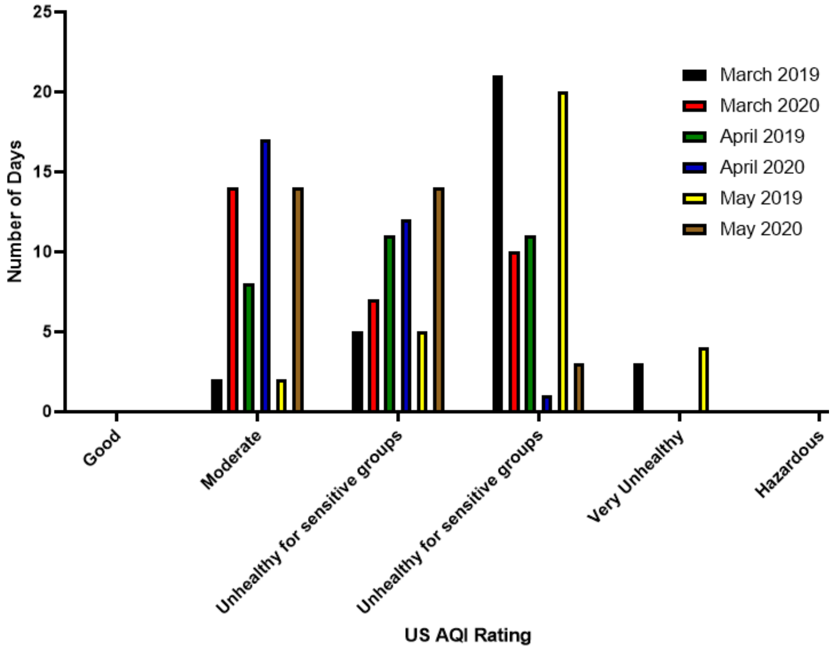


**Fig. 2b. Frequency of US AQI rating per year and month**

There is a stark difference between the mean $PM_{2.5}$ levels before and during COVID-19 curbing responses (Fig. 3) and these differences are statistically significant (Table 2). 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 2), 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.

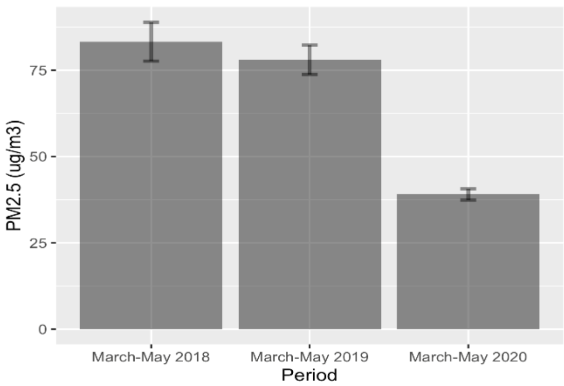


**Fig. 3. Mean and standard error $PM_{2.5}$ levels per period**

**Table 2. 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 |

## 4. 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 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 $10ug/m^3$ 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 service messages 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, 21,22].

## 5. CONCLUSION

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. 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. 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.

## 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).

## COMPETING INTERESTS

Author has declared that no competing interests exist.

## REFERENCES

1. Watts J, Kommenda N. Coronavirus pandemic leading to huge drop in air pollution. The Guardian; 2020.

Available:https://www.theguardian.com/environment/2020/mar/23/coronavirus-pandemic-leading-to-huge-drop-in-air-pollution.
Published 2020.
Accessed on 2020.

2. Davis S. Air pollution plummets by more than 45% in major European cities. Euro News; 2020.
Available:https://www.euronews.com/2020/04/16/air-pollution-plummets-by-more-than-45-in-major-european-cities.
Published 2020.
Accessed on2020.
Davidson J. India's Air Pollution Plummets in COVID-19 Lockdown. EcoWatch. 2020.
3. Available:https://www.ecowatch.com/india-air-pollution-coronavirus-2645617908.html?rebelltitem=3#rebelltitem3.
Published 2020.
Accessed on 2020.
4. Ahmed T. Significant drop in air pollution amid lockdown. The Express Tribune; 2020.
Available:https://tribune.com.pk/story/2238664/1-significant-drop-air-pollution-amid-lockdown.
Published 2020.
Accessed on 2020.
5. Rodríguez-Urrego D, Rodríguez-Urrego L. Air quality during the COVID-19: PM2.5 analysis in the 50 most polluted capital cities in the world. Environmental Pollution. 2020;266(Pt1):115042.
DOI: 10.1016/j.envpol.2020.115042
6. Adnan I. Lahore ranked world's most polluted city. The Express Tribune; 2020.
Available;https://tribune.com.pk/story/2104154/lahore-ranked-worlds-polluted-city.
Published 2019.
Accessed on October 18, 2020.
7. Rasheed A, Aneja V, Aiyyer A, Rafique U. Measurement and Analysis of Fine Particulate Matter (PM2.5) in Urban Areas of Pakistan. Aerosol Air Qual Res. 2015; 15(2):426-439.
DOI: 10.4209/aaqr.2014.10.0269
8. Air Quality in Lahore. IQAir; 2020.
Available:https://www.iqair.com/us/pakistan/punjab/lahore.
Published 2020.
Accessed on 2020.
9. Public Health: Sources and Effects of PM2.5. Department for Environment, Food and Rural Affairs; 2020.
Available:https://laqm.defra.gov.uk/public-health/pm25.html#:~:text=It%20can%20be%20either%20human,heating%20and%20in%20vehicle%20engines.
Published 2020.
Accessed on 2020.
10. Air Quality Monitoring. Environment Protection Department, Government of the Punjab; 2020.
Available:https://epd.punjab.gov.pk/air_quality. Published 2019.
Accessed on 2020.
11. US Consulates and Embassies. Air Now*;* 2020.
Available:https://www.airnow.gov/international/us-embassies-and-consulates/#Pakistan$Lahore.
Published 2020.
Accessed on 2020.
12. Air Quality Index Color Code Guide. United States Department of Agriculture. https://webcam.srs.fs.fed.us/test/AQI.shtml
Published 2020.
Accessed on: 2020.
13. Air Quality Reports 2018. Environment Protection Department, Government of the Punjab; 2020.
Available;https://epd.punjab.gov.pk/reports_2018
Published 2018.
Accessed on 2020.
14. Mishra P, Pandey CM, Singh U, Gupta A, Sahu C, Keshri A. Descriptive statistics and normality tests for statistical data. Annals of Cardiac Anaesthesia. 2019;22(1):67–72.
Available:https://doi.org/10.4103/aca.ACA_157_18
15. Talhelm T. What Is the Difference Between the PM2.5 and AQI Measurements?. SmartAir. 2020.
Available:https://smartairfilters.com/en/blog/difference-pm2-5-aqi-measurements/.
Published 2019.
Accessed on 2020.
16. Khanum F, Chaudhry M, Kumar P. Characterization of five-year observation data of fine particulate matter in the metropolitan area of Lahore. Air Quality, Atmosphere & Health. 2017;10(6):725-736.
DOI: 10.1007/s11869-017-0464-1
17. Lodhi A, Ghauri B, Khan M, Rahman S, Shafique S. Particulate matter (PM2.5) concentration and source apportionment in Lahore. J Braz Chem Soc. 2009;20(10): 1811-1820.
DOI: 10.1590/s0103-50532009001000007

18. Kommenda N, Carrington D. Air pollution in China back to pre-Covid levels and Europe may follow. The Guardian; 2020. Available:https://www.theguardian.com/environment/2020/jun/03/air-pollution-in-china-back-to-pre-covid-levels-and-europe-may-follow. Published 2020. Accessed on 2020.
19. Air Quality Life Index. Pakistan's Air Pollution Challenge & Potential for Longer Lives. Chicago: University of Chicago; 2019. Available:https://aqli.epic.uchicago.edu/wp-content/uploads/2019/02/Pakistan-Report.pdf Accessed on 2020.
20. Ambient (outdoor) air pollution. World Health Organization; 2020. Available:https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health. Published 2018. Accessed on 2020.
21. Riaz R, Hamid K. Existing Smog in Lahore, Pakistan: An Alarming Public Health Concern. Cureus; 2018. DOI: 10.7759/cureus.2111
22. U.S. Environmental Protection Agency. Air Quality Index - A Guide to Air Quality and Your Health. In Air Now. U.S. Environmental Protection Agency; 2014. Available:https://www.airnow.gov/sites/default/files/2018-04/aqi_brochure_02_14_0.pdf




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