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The changes in the air quality of Wazirpur, Delhi due to the COVID-19 shutdown

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ABSTRACT

The Corona Virus Disease (COVID)-19 pandemic led to the death of countless lives worldwide, which forced most countries and cities to impose a shutdown, bringing a halt to major human activities. While this shutdown caused a significant economic crisis, resulting in loss of livelihood to many people, it caused relief to the environment. Delhi in India is amongst the highest air-contaminated cities worldwide, and the COVID-19 shutdown helped improve air quality. This paper studied the variation in air quality for Wazirpur, Delhi, during shutdown in 2020 and a similar time-period in 2019. The data was acquired from the Central Pollution Control Board (CPCB) open-access portal for six air contaminants viz. Carbon-monoxide (CO), Nitrogen-dioxide (NO_2), Ozone (O_3), Particulate Matter (PM_{10} and $PM_{2.5}$), and Sulphur-dioxide (SO_2). Inferential statistical analysis was done to determine the trend in air quality variation during the shutdown compared to the previous year. Mean, standard deviation, percentage difference, linear regression and correlation analysis were made, and variable reduction in most air contaminants was noted. It was noted that for most of our observed time, the concentration of NO_2, O_3, PM_{10}, $PM_{2.5}$ and SO_2 in 2020 is lower than in 2019, while the concentration of CO is greater in 2020 than the corresponding time in 2019. The maximum decline was observed for PM10 (70.5%) during phase-1, while the maximum increase was observed in CO (32.3%) during phase-1. As the shutdown restrictions were eased out, an increase in the air contaminants was also noted.

Introduction

World Health Organization (WHO) declared Corona Virus Disease (COVID)−19 as a pandemic in March 2020, after it was first reported in December 2019 at Wuhan, China (Roser et al., 2020). It has been reported to spread in 210 countries, affecting over 11 million people and leading to the death of 4228,299 people worldwide as of 31st July 2021 (CDT, 2021). The government across the countries have taken several steps to fight the COVID-19 pandemic, such as testing for coronavirus infection, mandatory use of masque and sanitisers, social distancing, Personal Protective Equipment (PPE) kits, and most importantly, complete shutdown on local and national levels (Nigam et al., 2021). The shutdown has been imposed in different phases considering the spread of the virus and ensuring increased easiness in socio-economic activities in the less infected areas.

In India, the first officially reported COVID-19 patient was found in Kerala on 30th January 2020 (Andrews et al., 2020). The Indian government took unprecedented steps to avoid and control the spread of coronavirus, such as suspending non-critical international travels and shutting down Indian railways by mid of March 2020. A complete nationwide shutdown was enforced for 21 days on 24th March 2020. This shutdown was then extended in different phases, and the timeline for different phases is summarised in Table 1.

Along with the loss of life and health, COVID-19 brought socio-economic devastation for countries. The only blessing in disguise that could be extracted from this situation was the environment's healing. The United Nations (UN) believes that the environmental respite was temporary, and the environmental degradation reached back to its initial stage after the shutdown got over worldwide (UNDP, 2021). Nevertheless, air quality witnessed improvement for a considerable amount, and according to environmental scientists, greenhouse gas concentrations came down to levels not seen since World War II (He et al., 2020).

During the COVID-19 several countries in Europe (e.g. France. Germany, Italy, Spain) had closed construction activities, power plants, domestic and international travel, factories, industries, and other anthropogenic activities resulting in a sharp drop in air pollution (EEA, 2021; Zambrano et al., 2020). The changes in contaminants concentration during the shutdown imposed due to coronavirus outbreak in the Yangtze River Delta indicated that the restriction in manmade activities and industrial operations has led to a substantial decrease in Particulate Matter ($PM_{2.5}$), Nitrogen-dioxide (NO_2) and Sulphur-dioxide (SO_2) (Li et al., 2020). The air quality has improved significantly during the COVID-

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Table 1
COVID-19 shutdown phases in India (Source: Ministry of Home Affairs, Govt. of India).

India COVID-19 phase	Event	Date-2020
	India's First COVID-19 case reported	30th January
Phase-1	Nationwide shutdown	24th March to 13th April
Phase-2	Nationwide shutdown in green, orange and red zones Delhi under Red zone due to rising COVID-19 cases	14th April to 3rd May
Phase-3	Nationwide shutdown	4th May to 16th May
Phase-4	Nationwide shutdown. Relaxation allowed except in the red zone, which further converted into containment zone and buffer zone	17th May to 31st May
Phase-5	Unlock 1.0	1st June to 24th June

19 shutdown in the megacity of Hangzhou (Yuan et al., 2020). The United States also witnessed a decrement in the content of NO_2 (49%) and carbon-monoxide (CO)(37%) in the air because of the pandemic, which was correlated to the high population density (Chen et al., 2020).

The impact of the shutdown on the air quality of Rio de Janeiro, Brazil, was studied by analysing the air contaminants ($PM_{2.5}$, CO, NO_2, and Ozone (O_3)) in 2020 and the same time in the previous year (2019) (Dantas et al., 2020). The three primary air contaminants (PM_{10}, NO_2 and CO) reduced significantly due to enforcement of social distancing in heavily inhabited cities like São Paulo and Rio de Janeiro (Siciliano et al., 2020). In the town of Sale (northwestern Morocco), some changes in air contaminant levels were observed because of strict measures to restrict human movement and prohibit all non-essential activities (Otmani et al., 2020).

Using the remote sensing data set obtained from the ESA Tropospheric Monitoring Instrument (TROPOMI) and locally observed data, the air quality of Barcelona was studied (Tobías et al., 2020). The study concluded 31% and 51% reduction in NO_2 and $PM_{2.5,}$ respectively, during the pandemic shutdown. The National Aeronautics and Space Administration (NASA) reported a decrease in NO_2 by 10–30% in central and eastern China at the beginning of 2020 using TROPOMI sensors (Patel, 2020). In the California basin, an uneven trend of O_3 concentration and a 27% reduction in NO_2 was observed during the shutdown compared to the past five years (Parker et al., 2020).

According to recent studies, during the COVID-19 shutdown in India, most air contaminants were reduced throughout the country. After implementing shutdown, a survey of 12 cities in the Indo-Gangetic Plain (IGP) found a significant drop (35%) in $PM_{2.5}$ content in the air throughout the towns in the IGP (Das et al., 2020). During the initial days of phase-1 COVID-19 shutdown, the level of the contaminants in Delhi fell to a 5-year low, with $PM_{2.5}$ concentrations falling to 42 g/m^3 (equivalent to March 2016 values) (Jacob, 2021). Compared to the previous year, the air quality index (AQI) in Delhi decreased by 49%, resulting in a 60% improvement in the industrialisation and transportation hub (Mahato et al., 2020). $PM_{2.5}$ witnessed the most significant reduction compared to other air contaminants during the shutdown period in Gaya, Kanpur, Nagpur, and Kolkata (Sharma et al., 2020). During the first and second phases of the COVID-19 shutdown in Chandigarh, variance in ambient air quality showed considerable decreases in all air contaminants (Mor et al., 2020). During the post-shutdown phase, the content of PM_{10}, $PM_{2.5}$, NO_2, and SO_2 in Delhi air decreased by 55%, 49%, 60%, and 19%, respectively, resulting in significant improvements in air quality (Kumari and Toshniwal, 2020). In Kolkata city, there was a reduction in the mean content of the primary air contaminants during the shutdown period (Sarkar et al., 2020). A similar study found a considerable decrease in the concentration of PM_{10}, $PM_{2.5}$, and NO_2 during the COVID-19 shutdown in 16 cities identified as hotspot regions comprising nearly two-thirds of India (Garg et al., 2021). In Gujarat's Saurashtra and South Gujarat regions, NO_2 concentrations were lowered by 30–84%, while O_3 increased by 16–48% due to the reduction in NO_2. On average, AQI readings in major cities in Gujarat (e.g. Ahmedabad, Gandhinagar, Jamnagar, and Rajkot) dropped by 58% (Selvam et al., 2020). The level of air pollution (NO_2, $PM_{2.5}$, and PM_{10}) in Ahmedabad improved significantly, indicating that the COVID-19 shutdown positively impacted the environment (Aman et al., 2020).

In this study, the air pollution of Wazirpur, Delhi, during the shutdown imposed because of COVID-19 was investigated. Warizpur is an important industrial area of Delhi with large scale steel factories, and air pollution is a severe problem. Even though studies have shown reduced air pollution because of the COVID-19 shutdown worldwide, no study has investigated the impact of the shutdown on air pollution of Wazirpur. In addition, this study uses various statistical tools to make data visualisation easy and simple. Also, this study has analysed the phase-wise effect of COVID-19 on air pollution, which is novel and limited in the literature. Most studies available in literature did not study the phase-wise effect of the shutdown, and if at all, then restricted to initial phases of shutdown only. The current study considers air contaminant observation during all five stages of the shutdown, indicating improved air quality because of shutdown measures. This study can be helpful for government agencies to control anthropogenic activities even for a short duration to reduce air pollution considerably.

Study area

Fig. 1 shows the location of Wazipur in Northern India, which is one of the 70 assembly constituencies of Delhi. It lies in Chandni Chowk (Lok Sabha constituency). It is situated at latitude 28.70° N and longitude 77.16° E. It is fenced by Indo-Gangetic plains on the north-eastern side, Aravalli ranges on the southern side, and Indian Thar desert on the western side. It is drained by the Yamuna sub-basin, which flows in the north-south direction (Agarwal et al., 2021). It is dominated by three main geomorphic units, i.e. rocky surface, older alluvium plain and flood plains of Yamuna (Gupte, 2019). The local hydrogeological conditions mainly govern the groundwater conditions, and it is controlled by a mix of rainfall, river, canal water, and irrigation return flows (Central Ground Water Board, 2018). The population of Delhi had an increased rate of 2.1% per annum between 2001 and 2011. Assuming the same growth rate, Delhi's 2020 population is estimated at 18.4 million (ESD, 2021). All these physiographic and demographic conditions directly affect the air quality of Delhi and all its 70 constituencies.

Wazirpur is a heavily industrialised region in Delhi's northwestern outskirts. It is well-known for its stainless-steel factories, which supply tons of steel vessels to India and abroad. It also makes industrial steel containers such as boilers, vessels, and large steel pots. This industry is well-known worldwide because of the volume it generates, and many prominent New Delhi locales, including business and residential regions, surround it. The primary commercial area adjacent is the Wazirpur commercial complex, mainly consisting of IT hardware and software businesses and showrooms. Hence, it is known as the computer market and is becoming increasingly well known as a growing hardware market (WIA, 2021). It is marked by extreme dry hot summer and extreme cold winter climatic conditions. The temperature varies from a minimum of 7.3° in winter to a maximum of 47° in summer and receives a mean annual rainfall of 611.8 mm (WIA, 2021).

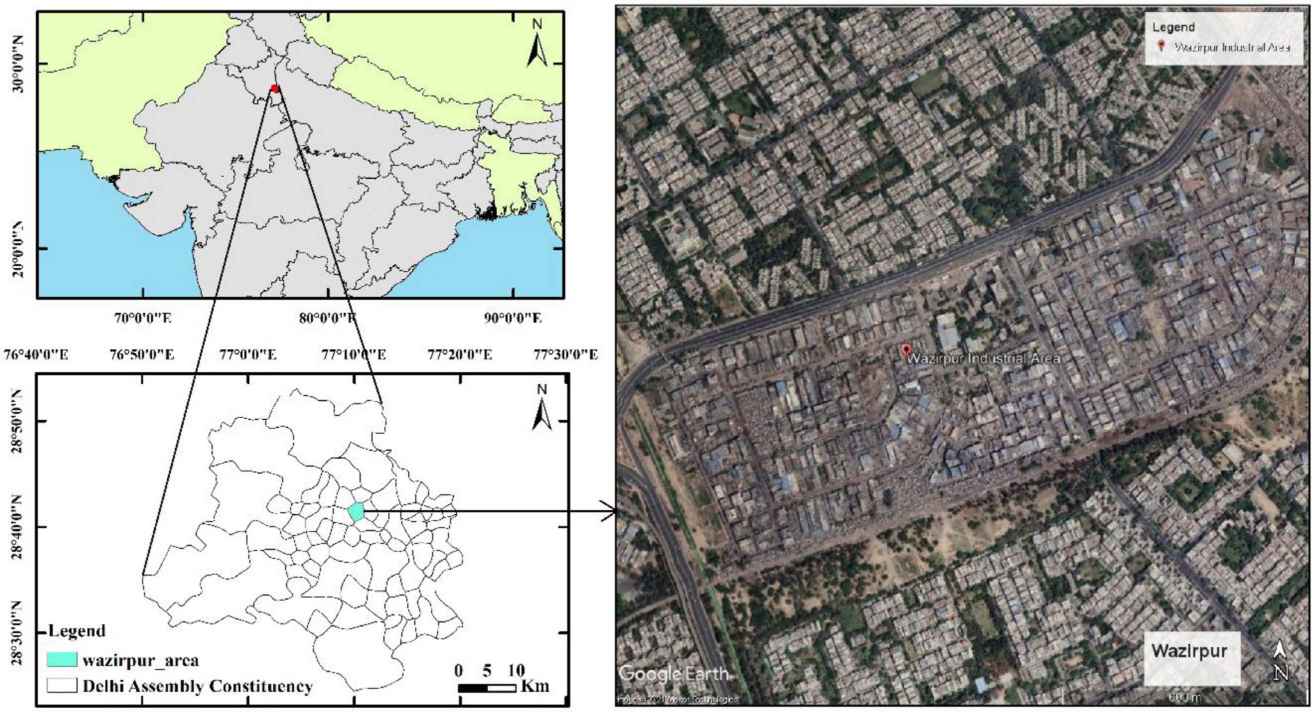

Fig. 1. Location of Wazirpur, Delhi amongst the 70 assembly constituencies of Delhi. Also, the google image of Wazirpur is shown, highlighting its densely urban fabric.

Material and methods

In 2016, the Indian government launched the 'National Air Quality Index (NAQI)' as part of its 'Swacch Bharat Mission', and the Central Pollution Control Board (CPCB) issues a daily NAQI bulletin (NAQI, 2015). The daily NAQI, Government of India data portal (AQM, 2021), was used to download the concentration values of 6 air contaminants (CO, NO_2, O_3, PM_{10}, $PM_{2.5}$, SO_2) between 24th March to 24th June for 2019 and 2020. Under the NAQI, the averaging time for pollutants such as: $PM_{2.5}$, PM_{10}, NO_2, and SO_2 is 24-h whereas, O_3 and CO have the averaging time of 1-h.

The overall shutdown period was broken into five phases based on different time-period for which the Indian government enforced different intensities of the shutdown. For the public, each shutdown phase imposed different rules and regulations. The first phase was the most intense, which included complete limitations on all non-essential operations, and was enforced from 23rd March 2020, to 13th April 2020.

During the shutdown phase-2, which was implemented for 19 days from 14th April 2020 to 3rd May 2020, different areas of the country were differentiated into colour zones (green, orange and red) based on the count and intensity of COVID-19 patients. The red zones, which witnessed rapidly increasing coronavirus patient cases, were completely shutdown. In contrast, the orange zones, which saw coronavirus patient cases in a controlled amount, were given some leeway. The green zone, which witnessed the least coronavirus patient cases, had the fewest limitations.

The third phase was imposed between 4th May 2020 and 16th May 2020, while the fourth phase was imposed from 17th May 2020 to 31st May 2020. The fourth phase was the final shutdown period at the state level and set transition from colour-coded zones to local containment and buffer zones. On 1st June 2020, the unlock 1.0 (also known as 'phase-5′ in the study) began, with various restrictions loosened everywhere except containment zones. Due to the resumption of different economic operations in the cities, variances in the severity of limitations enforced during distinct shutdown periods directly affected the variability in air purity.

The mean differences were calculated with descriptive statistical approaches to identify the variability in the concentration of air contaminants during the various stages of shutdown as compared to the same time-period in the previous year. Additionally, minimum, maximum, and standard deviation were summarised to determine the fluctuation of air contaminants. Correlation analysis was done to highlight the bivariate relationships amongst pairs of air contaminants for 2019 and 2020 for Wazirpur city. Finally, a linear regression analysis was used to see how the Air Quality Index (AQI) levels correlated with the distinct shutdown phases, which was calculated as below (NAQI, 2015):

$$I_C = \left(\frac{I_{HI} - I_{LO}}{BP_{HI} - BP_{LO}} \times (C_C - BP_{LO}) \right) + I_{LO}$$

where I_C is the AQI for contaminant 'C', C_C is the actual ambient concentration of contaminants' C', BP_{HI} is the concentration breakpoint that is greater than or equal to C_C, BP_{LO} is the concentration breakpoint that is less than or equal to C_C, I_{HI} is the AQI value corresponding to BP_{HI}, and I_{Lo} is the AQI value corresponding to BP_{LO}. Table 2 provides the value of breakpoints used.

The colour codes in the daily breakpoint table are based on the AQI numerical values. AQI between 0 and 50 shows that the air quality is good, doesn't have any adverse effect on humans, and is represented by a dark green colour. Similarly, AQI between 51 and 100 shows that the air quality is satisfactory (light green), can cause small breathing problems, while AQI between 101 and 250 are classified as moderately polluted (yellow), 251–350 are classified as poor (orange), 351–430 are classified as very poor (light red), and AQI between 431 and 500 are classified as severe (dark red) (AQM, 2021).

Results

The temporal plots for the daily mean distribution of six air contaminants (CO, NO_2, O_3, PM_{10}, $PM_{2.5}$, SO_2) for Wazirpur city during COVID-19 shutdown in 2020 and the same time-period in 2019 is shown in Fig. 2. The phase-wise difference in mean and standard deviation (as percentage) of concentration of air contaminants between 2020 and

Table 2
Breakpoints for Air Quality Index (AQI) Scale. Source: Central Pollution Control Board (NAQI, 2015).

AQI Category	AQI Range	PM_{10} (24 hr) (μg/m3)	$PM_{2.5}$ (24 hr) (μg/m3)	NO_2 (24 hr) (μg/m3)	O_3 (8-hr) (μg/m3)	CO (8-hr) (mg/m3)	SO_2 (24 hr) (μg/m3)
Good	0–50	0–50	0–30	0–40	0–50	0–1	0–40
Satisfactory	51–100	51–100	31–60	41–80	51–100	1.1–2.0	41–80
Moderate	101–250	101–250	61–90	81–180	101–168	2.1–10	81–380
Poor	251–350	251–350	91–120	181–280	169–208*	10.1–17	381–800
Very Poor	351–430	351–430	121–250	281–400	209–748*	17.1–34	801–1600
Severe	431–500	430+	250+	400+	748+*	34+	1600+

* One hourly monitoring.

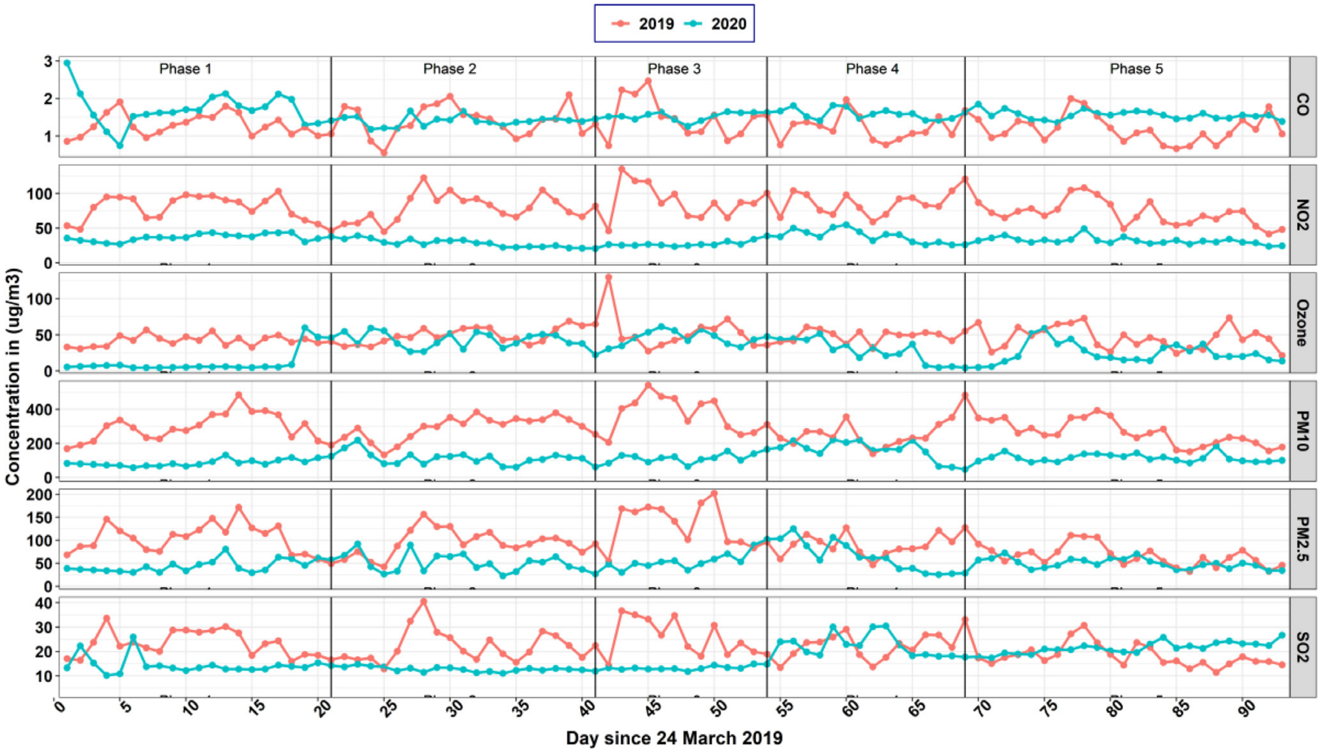

Fig. 2. Temporal Variation of mean concentrations of air contaminants for COVID-19 shutdown period in 2020 and same period in 2019 for Wazirpur, Delhi.

Table 3
Mean difference and standard deviation difference observed during different shutdown phases of 2020 in comparison to the same period in 2019 for Wazirpur.

Period	$PM_{2.5}$		PM_{10}		NO_2		SO_2		CO		O_3	
	Mean diff (%)	SD diff (%)	Mean diff (%)	SD diff (%)	Mean diff (%)	SD diff (%)	Mean diff (%)	SD diff (%)	Mean diff (%)	SD diff (%)	Mean diff (%)	SD diff (%)
Phase-1	−56.8	−57.9	−70.5	−75.1	−53.4	−71.9	−37.9	−32.9	32.3	52.6	−70.2	122.9
Phase-2	−46.8	−27.2	−61.6	−41.9	−64.9	−70.7	−42.8	−85.3	−0.7	−67.0	−15.4	−1.1
Phase-3	−56.9	−56.4	−68.9	−72.8	−68.8	−82.7	−47.8	−88.4	2.8	−78.1	−14.1	−62.1
Phase-4	−30.6	37.0	−39.1	−31.3	−55.8	−43.6	−0.2	−15.7	29.9	−58.6	−44.5	92.9
Phase-5	−24.6	−50.8	−56.1	−67.3	−55.3	−70.2	18.4	−48.4	31.4	−67.7	−46.1	−13.5

2019 for Wazirpur during the shutdown is shown in Table 3. The phase-wise statistical summary of each contaminant for both the years 2019 and 2020 is provided in Table 4.

Fig. 2 shows that for most of our observed time, the concentration of NO_2, O_3, PM_{10}, $PM_{2.5}$ and SO_2 in 2020 is lower than in 2019, while concentration of CO is greater in 2020 than corresponding time in 2019. From Table 3, it can be noted that the maximum decline was observed for PM_{10} (70.5%) during phase-1, while the maximum increase was observed in CO (32.3%) during phase-1. $PM_{2.5}$ decreased by 56.8% during phase-1 and recovered by 32.2% during unlock 1.0 (phase-5). NO_2 concentration in air in 2020 decreased by 53.4% and 68.8% during phase-1 and phase-3, respectively. The maximum decline in SO_2 was in phase-2 (42.8%), but its content increased to 18.4% during the unlock 1.0 as compared to the corresponding period of 2019. The decremental rate of O_3 ranged between 14.1% and 70.2% during phase-3 and phase-1, respectively, while the CO concentration in the air increased or almost remained the same for all the phases despite the shutdown.

Fig. 3 depicts a scatterplot, a graphical representation of the Pearson correlation matrix, that evaluates air contaminant variations and illustrates bivariate connections between pairs of air contaminants for Wazirpur city from pre-COVID-19 (2019) to COVID-19 (2020). The covariation matrix plot allows multiple pairs of air contaminants to be investigated altogether. For both the years 2019 (Fig. 3a) and 2020 (Fig. 3b), the air contaminants NO_2, SO_2, CO, and O_3 are positively correlated with particulate matter ($PM_{2.5}$ and PM_{10}). NO_2 also has a positive relationship with SO_2 and CO, while O_3 depicts a negative cor-

Table 4
Variation air contaminants concentrations for pre-COVID-19 (2019) and COVID-19 (2020) years.

Contaminant	Phase-1 (shutdown 1.0)				Phase-2 (shutdown 2.0)				Phase-3 (shutdown 3.0)				Phase-4 (shutdown 4.0)				Phase-5 (Unlock 1.0)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
2019																				
$PM_{2.5}$	103.5	32.5	49.7	171.6	95.3	27.9	42.3	156.8	132.8	46.2	54.7	202.3	90.7	23.9	47.0	127.9	66.1	22.5	32.6	111.0
PM_{10}	294.0	82.8	169.0	486.5	294.1	66.9	133.2	384.9	374.9	103.2	207.0	542.7	261.5	85.7	139.5	483.7	262.6	73.4	152.1	394.6
NO_2	78.8	18.2	46.3	103.2	79.9	19.1	44.9	122.8	89.2	25.0	46.0	135.1	86.4	17.1	59.1	121.0	71.4	17.6	41.6	108.3
SO_2	23.2	5.2	16.0	33.6	22.3	6.6	12.9	40.6	25.6	7.7	14.4	36.7	22.5	5.5	13.5	33.1	18.2	4.5	11.4	30.8
CO	1.3	0.3	0.9	1.9	1.4	0.4	0.6	2.1	1.5	0.5	0.8	2.5	1.2	0.3	0.8	2.0	1.2	0.4	0.7	2.0
O_3	42.0	7.3	30.9	56.9	49.8	11.1	33.5	69.0	53.2	26.0	27.5	129.9	48.7	8.4	31.1	61.0	46.2	15.9	21.5	73.6
2020																				
$PM_{2.5}$	44.7	13.7	29.6	80.8	50.7	20.3	23.0	92.3	57.2	20.1	30.4	102.5	63.0	32.8	25.7	125.5	49.8	11.1	33.9	72.8
PM_{10}	87.7	20.6	58.3	132.7	112.8	38.8	60.9	219.5	116.7	28.1	64.9	165.3	159.3	58.9	47.9	222.3	115.3	24.0	85.9	184.9
NO_2	36.7	5.1	26.9	44.0	28.0	5.6	20.7	39.4	27.8	4.3	23.6	38.8	38.1	9.7	25.8	54.9	32.0	5.2	23.8	49.3
SO_2	14.4	3.5	10.3	25.9	12.7	1.0	11.1	14.8	13.4	0.9	11.8	14.9	22.4	4.6	17.7	30.4	21.5	2.3	17.4	26.7
CO	1.7	0.4	0.8	3.0	1.4	0.1	1.2	1.7	1.5	0.1	1.3	1.7	1.6	0.1	1.4	1.8	1.6	0.1	1.4	1.9
O_3	12.4	16.3	4.6	59.8	42.1	11.0	22.3	59.4	45.7	9.9	30.8	61.4	27.0	16.1	4.5	51.8	24.9	13.7	5.0	59.2

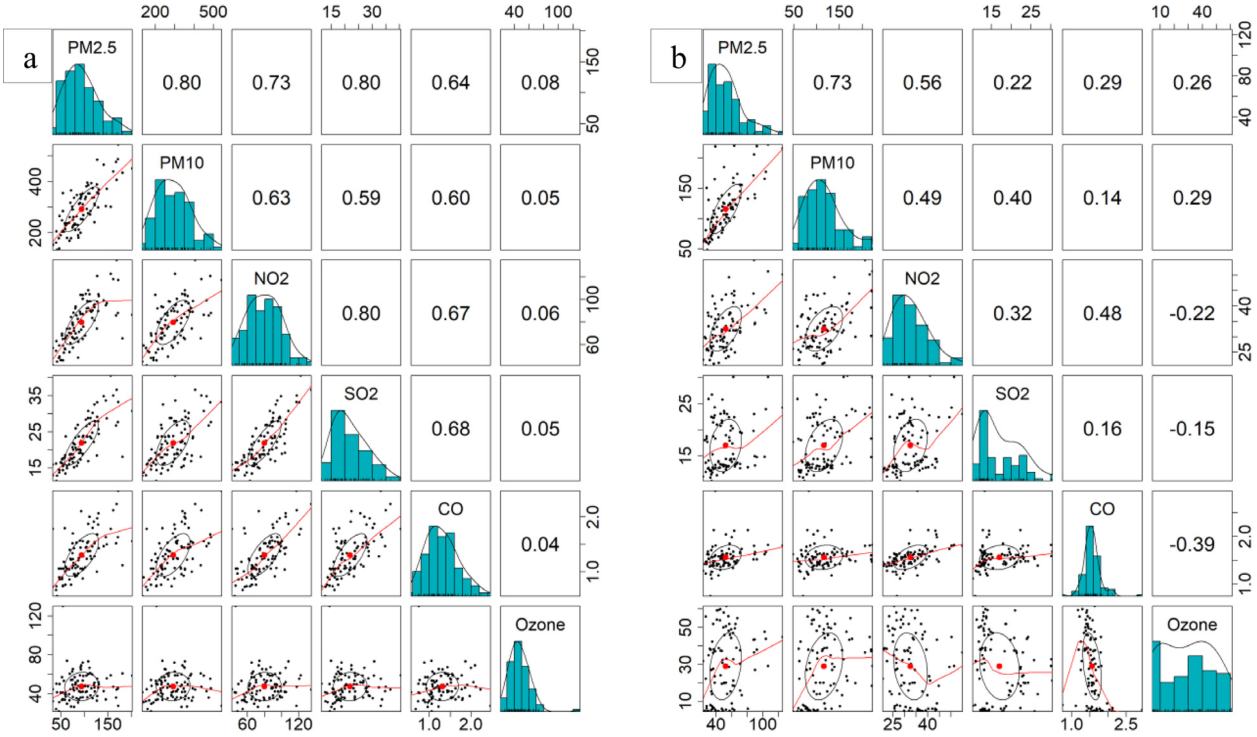

Fig. 3. Correlation matrix scatter plot of the air contaminants a) 2019 (Pre- COVID-19) b) 2020 (COVID-19)for Wazirpur.

relation with NO_2, SO_2 and CO for both the years 2019 and 2020. The highest correlation coefficient in 2019 is 0.80 between $PM_{2.5}$ and PM_{10}, while that in 2020 is 0.73 between $PM_{2.5}$ and PM_{10}, which means that if $PM_{2.5}$ increases, the PM_{10} also increases.

Fig. 4 shows the temporal distribution of the air quality index (AQI) during shutdown days of 2020 and the corresponding days in 2019. The AQI in 2020 is lower than AQI in 2019, which shows that the air pollution in Wazirpur decreased because of the shutdown imposed during COVID-19. Also, for the years 2019 and 2020, linear regression shows a negative and positive correlation, respectively, between the daily AQI and shutdown days. The findings of this study are consistent with those of other recent studies conducted in other places throughout the world, e.g. USA (Chen et al., 2020); China (Nie et al., 2020; Shi and Brasseur, 2020; Yuan et al., 2020); Brazil (Dantas et al., 2020); Italy (Popescu and Lonel, 2010) and India (Sharma et al., 2020).

Discussion

Environmental degradation due to air pollution is a severe problem in many of the world's major cities and industrialised areas. In India, unplanned development has resulted in many issues, including soil degradation and deterioration of air-water quality, particularly in metropolitan areas. The underlying reasons for the fast increment in air pollution are incomplete burning of fossil fuels by cars and industrial operations and poor disposal of anthropogenic waste (Popescu and Lonel, 2010). The COVID-19 pandemic in March 2020 enforced a nationwide shutdown in India to prevent infection. The various phases of shutdown lasted 68 days, after which the regulations were eased out. The closure of anthropogenic activities provided a chance for the ecosystem to repair itself from victimisation by human activities, albeit only temporarily (UNDP, 2021).

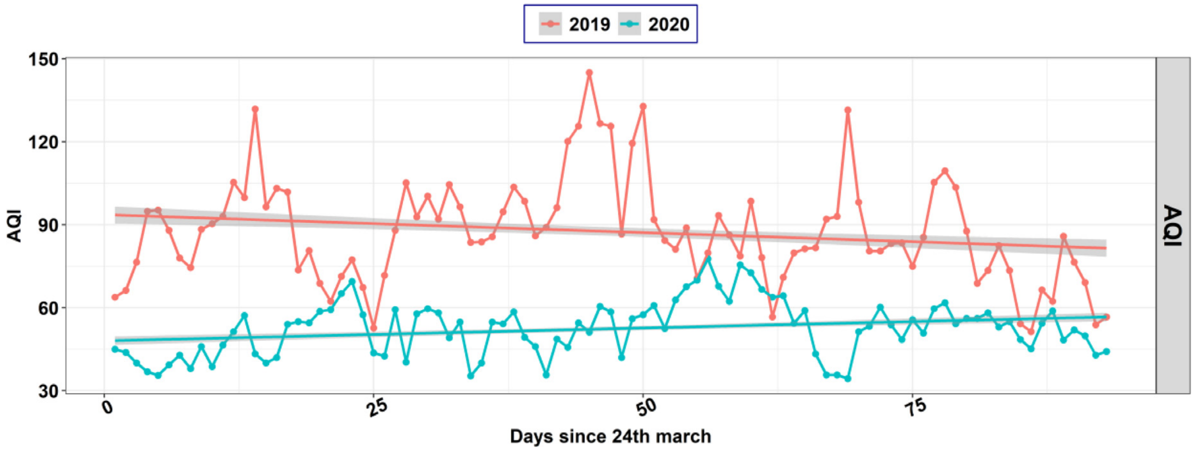

Fig. 4. Temporal distribution of air quality index (AQI).

The current study, which examines the effect of the COVID-19 shutdown on air quality in Wazirpur, India, backs up previous research. During phase-1, the city saw a decrease in PM_{10} (mainly generated by automobiles) and $PM_{2.5}$ (induced by dust, ash, and other factors) (NAQI, 2015) concentrations with respect to the corresponding period in 2019 (Fig. 2). The most plausible reason is that all vehicular movements and industrial activity were prohibited during the shutdown. A similar substantially declining pattern was seen for SO_2, which is mainly produced by transportation and oil refineries (Chaudhary et al., 2008; Tripathi and Gautam, 2007). NO_2 is primarily generated by heavy vehicles (USEPA, 2021) and shows a consistent decrease during the COVID-19 shutdown as compared to the previous year, which could be attributed to curbing the movement of all heavy vehicles during the shutdown. The O_3 content also decreased during phase-1 of the shutdown but while concentration of other contaminants decreased in air during the shutdown, the concentration of CO increased in the city during all phases of the shutdown. The CO is often created by incomplete combustion of carbon-containing fuels (Council, 2002), and various home appliances like unvented kerosene and gas space heaters, leaking chimneys and furnaces, and gas stoves. The increased pressure on indoors, as compared to previous year could be the reason for rise in CO concentration in Wazirpur air despite the shutdown. Also, the pharmaceutical industries in and nearby the cities operated at full capacity to support the rising number of COVID-19 patients, which could have raised the CO concentration.

Phase-2 shutdown lasted 14 days, during which the content of $PM_{2.5}$, PM_{10}, SO_2, and NO_2 in the air decreased, while the O_3 level remained similar to the previous year. The increase in O_3 concentration in phase-2 compared to phase-1 could be attributed to a drop in NO2 as a decrease in NOx can increase O_3 due to nonlinear relationships just above the ground level (Sillman, 1999). Economic activities were gradually resumed during phase-3, as limitations were removed, resulting in an upward trend in the concentration of contaminants.

$PM_{2.5}$ and PM_{10} concentrations increased during phase-4 (shutdown) and phase-5 (unlock-1), owing to the relaxation of restrictions on human activities. Wazirpur is famous for its stainless-steel factories, which supply tons of steel vessels to India and abroad. Also, the city has big pharmaceuticals like Remedis, Charaksutra, Coventic, and JVS Pharma. While the pharmaceuticals operated at their full capacity, the stainless-steel factories were allowed to work with limited production in phase-4 and phase-5 after ensuring social distancing. Along with these, the key sectors contributing to air pollution in phase-4 and phase-5 were transportation, traffic, industries, construction, road dust re-suspension, residential activities, landfill fires and restaurant cooking (Cusworth et al., 2018).

Fig. 5 depicts the average AQI for each phase during the shutdown and pre-shutdown year. Clearly, the 2020 AQI is lower than the 2019 AQI for all the phases, demonstrating that because of the COVID-19 shutdown, air quality has improved dramatically in each phase. In phase-4 and phase-5 of the year 2020, the AQI has risen compared to prior phases. It is due to the relaxation of the shutdown limitations, which resulted in increased vehicular and industrial activity, leading to increased air pollution. This could also be observed from the temporal variation of AQI (Fig. 4), where the linear regression analysis for the year 2020 shows a positive slope, as the values of AQI in phase-4 and phase-5 have increased owing to relaxation in restrictions.

The results in this study broadly highlight that the air quality in Wazirpur improved during the shutdown and then again started to deplete once the restrictions were eased out, but the variations in different contaminants were not consistent. There are two fundamental factors for the varying trajectories of different contaminants. First, the number of on-road vehicles changed in each phase, and the industrial setup is diverse for Wazirpur city (WIA, 2021). The bulk of pharmaceutical production and stainless-steel plants are located in and near the city, which indirectly impacts the emission of various contaminants (depending on the raw materials used in processing) and the transportation of completed products to the market. Second, the study area's landlocked geography, rainfall pattern, and proximity to the Yamuna River influence contaminant mixing and fluctuation. These factors can explain discrepancies in the rate of reduction and increase in the concentration of different contaminants.

The results discussed in this paper are consistent with the published literature. The metropolitan cities worldwide, where restrictions were imposed due to COVID lockdown, showed similar behaviour. Nie et al., 2020 reported several health advantages in 31 Chinese provincial capital cities where NO_2 levels were reduced due to COVID lockdown. NO_2, SO_2, and PM_{10} are prevalent air contaminants in industrialised cities, and they cause cardiovascular and respiratory disorders (Koken et al., 2003; LeTertre et al., 2002). In 2019, the Indian Ministry of Earth, Forestry, and Climate Change (MoEFC) unveiled a five-year action plan under its National Clean Air Program (NCAP) to reduce $PM_{2.5}$ and PM_{10} concentrations nationally by 30% (MoEFC, 2021). Delhi, the country's capital, is densely inhabited and one of the most polluted cities, where vehicle emissions, road dust, factories, industries, and building sites all contribute to pollution (Hindu, 2020). Sharma et al., 2020 observed a substantial decrease in air pollution in 88 cities due to the obligatory shutdown imposed in India. Nigam et al., 2021 found that different industrial setups in Gujarat played a vital role in air pollution trends during COVID-19 lockdown, similar to results obtained in this research.

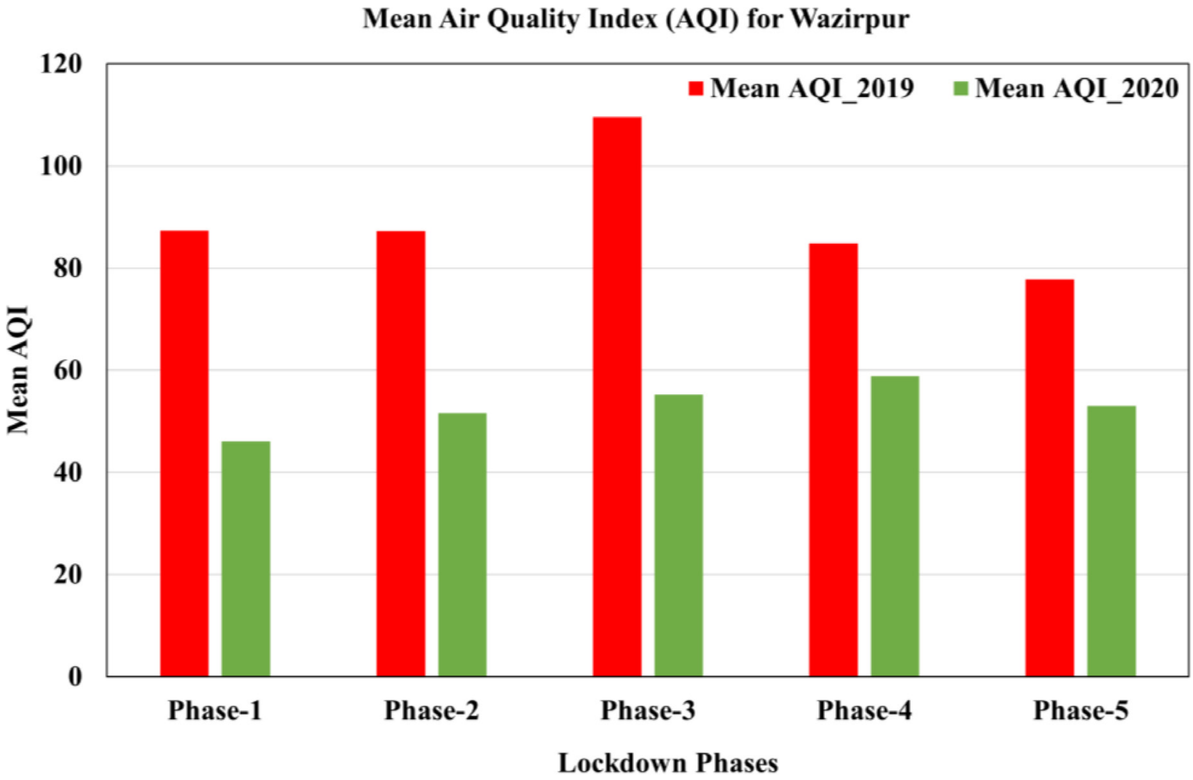

Fig. 5. Mean Air Quality Index for Wazirpur for 2019 and 2020 during different shutdown.

Instead of using predicted scenarios, the world's greatest shutdown event has presented a genuine illustration of how contaminants might change due to various economic constraints. People accepted the limits imposed by the shutdown because they were afraid of illness. As a result, various levels of pollution reduction could be achieved. Although climatic circumstances (particularly rainfall) may play a role in reducing air pollution levels, rainfall has a minimal impact on the current study location because no significant rainfall change was documented during the study period. The impact of weather conditions should not be overlooked and can be considered in the future when analysing long-term patterns. As seen in previous research and the current study, there is an apparent reduction in contaminant levels because of COVID-19 related shutdown, which improves air quality in most parts of the world.

Conclusions

The shutdown procedures enforced to restrict the COVID-19 pandemic improved the air quality as a blessing in disguise, as evidenced by this study and others in several cities. The shutdown has not only slowed the spread of infection, but it has also provided an opportunity to achieve the environment's and health's restoration potential, thanks to lower levels of ambient air contaminants and improved air quality.

India's courageous decision to implement severe shutdown restrictions despite economic costs resulted in a significant improvement in air quality. The air quality data of Wazirpur is used in this study to analyse the variation in different contaminants during all the COVID-19′s shutdown phases. The findings demonstrated various patterns from slow to quick reductions in most contaminant concentrations and an increase in O_3 concentration due to a substantial decrease in NO_2 in Phase-2. . It was noted that for most of our observed time, the concentration of NO_2, O_3, PM_{10}, $PM_{2.5}$ and SO_2 in 2020 is lower than in 2019, while concentration of CO is greater in 2020 than corresponding time in 2019. The maximum decline was observed for PM10 (70.5%) during phase-1, while the maximum increase was observed in CO (32.3%) during phase-1. As the shutdown restrictions were relaxed during phase-4 and unlock-1, other contaminants increased as well.

The enforced regime was unquestionably damaging to the economy; however, a modified mode of various economic reservations might be utilised to limit pollution levels on a case-by-case basis. The current study's findings suggest that air pollution mitigation methods could be planned. The importance of the hour for policymakers is to appreciate the function of the shutdown in reducing air pollution and not to lose the unintentionally gained lead against growing air pollution to critical levels during this period. It is hoped that the current scenario will broaden human perceptions of the negative consequences of the human activities.

Declaration of Competing Interest

The authors declare no conflicts of interest.

CRediT authorship contribution statement

Vivek Agarwal: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Amit Kumar:** Formal analysis, Software, Validation, Investigation, Visualization, Writing – review & editing.

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Data availability statement

The datasets generated during and/or analysed during the current study are available in the Central Pollution Control Board (CPCB) repository, [https://app.cpcbccr.com/AQI_India/].

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