B.Sc.(Hons.) STATISTICS

Effect of COVID-19 lockdown on India's air quality

Can lockdown spark a clean environment?

RAMANUJAN COLLEGE
NAAC 'A' ACCREDITED
UNIVERSITY OF DELHI

Submitted to

Department of Statistics
(Ramanujan College)
University of Delhi

Submitted by

Nishant Singh
Prakhar Binjola
Chirag Kohli
Rakesh Kr. Bairwa

Table of Contents

Abstract

COVID-19 also known as the coronavirus is an ongoing pandemic of coronavirus disease 2019 (COVID-19) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The outbreak was first identified in Wuhan, China, in early December 2019. Drastic measures such as lockdowns taken by countries worldwide to contain the spread of COVID-19 have influenced air pollution dynamics substantially, at a planetary scale. Several media reported the lockdown-induced air pollution reduction based on quickly assembled satellite observations. However, a detailed analysis of such reduction in air pollution backed by quality data collected from ground stations across India and the effects of lockdown to it are still missing. Here, we investigate changes in concentrations of three air pollutants: $PM_{2.5}$, NO_2 and SO_2 in 5 Indian cities from January to April in 2018, 2019 and 2020. The mean monthly concentrations of NO_2 and SO_2 in March and April of 2020 were found consistently lower than in 2019 in most of the cities. After lockdown, declines of anthropogenic pollutants such as NO_2 concentrations were seen in 5 cities. Improvement in air quality following lockdown was observed in India's most polluted cities including Delhi, Lucknow, Mumbai and Jaipur. More visible reduction of air pollution remains to be seen as the lockdown is prolonged. Nevertheless, such reductions are expected to be temporary because the levels are likely to go up again once the situation gets back to normal.

Background and Significance

The worldwide disruption caused by the COVID-19 pandemic has resulted in numerous impacts on the environment and the climate. The severe decline in planned travel has caused many regions to experience a drop in air pollution. In China, lockdowns and other measures resulted in a 25 per cent reduction in carbon emissions and a 50 per cent reduction in nitrogen oxide emissions, which one Earth systems scientist estimated may have saved at least 77,000 lives over two months.

Reducing air pollution can reduce both climate change and COVID-19 risks but it is not yet clear which types of air pollution (if any) are common risks to both climate change and COVID-19. The Centre for Research on Energy and Clean Air reported that methods to contain the spread of coronaviruses, such as quarantines and travel bans, resulted in a 25 per cent reduction in carbon emission in China. In the first month of lockdowns, China produced approximately 200 million fewer metric tons of carbon dioxide than in the same period in 2019, due to the reduction in air traffic, oil refining, and coal consumption. One Earth systems scientist estimated that this reduction may have saved at least 77,000 lives. However, Sarah Ladislaw from the Center for Strategic & International Studies argued that reductions in emissions due to economic downturns should not be seen as beneficial, stating that China's attempts to return to previous rates of growth amidst trade wars and supply chain disruptions in the energy market will worsen its environmental impact. Between 1 January and 11 March 2020, the European Space Agency observed a marked decline in nitrous oxide emissions from cars, power plants, and factories in the Po Valley region in northern Italy, coinciding with lockdowns in the region.

NASA and ESA have been monitoring how the nitrogen dioxide gases dropped significantly during the initial Chinese phase of the COVID-19 pandemic. The economic slowdown from the virus drastically dropped pollution levels, especially in cities like Wuhan, China by 25-40%. NASA uses an ozone monitoring instrument (OMI) to analyze and observe the ozone layer and pollutants such as NO_2, aerosols and others. This instrument helped NASA to process and interpret the data coming in due to the lockdowns worldwide. According to NASA scientists, the drop in NO_2 pollution began in Wuhan, China and slowly spread to the rest of the world.

Joint research led by scientists from China and the U.S. estimated that nitrogen oxide (NOx=NO+NO2) emissions decreased by 50% in East China during 23 January (Wuhan lockdown) - 9 February 2020, compared to 1 January - 22 January 2020. Emissions then increased by 26% from 10 February (back-to-work day) - 12 March 2020, indicating possible increasing socioeconomic activities after most provinces allowed businesses to open. It is yet to be investigated what COVID-19 control measures are most efficient in controlling virus spread and least socioeconomic impact.

COVID-19 in India

The first case of the COVID-19 pandemic in India was reported on 30 January 2020, originating from China. The infection rate of COVID-19 in India is reported to be 1.7, significantly lower than in the worst-affected countries.

On 22 March 2020, India observed a 14-hour voluntary public curfew at the instance of prime minister Narendra Modi. The government followed it up with lockdowns in 75 districts where COVID-19 cases had occurred as well as all major cities. Further, on 24 March, the prime minister ordered a nationwide lockdown for 21 days, affecting the entire 1.3 billion population of India. On 14 April, the prime minister extended the ongoing nationwide lockdown till 3 May.

India is home to 21 of the world's 30 most polluted cities, but recently air pollution levels have started to drop dramatically.

While the complete shutdown of India's economy was designed to stop the spread of COVID-19, it is having an ancillary health benefit of clearing the air that millions of people were choking on, according to CNN. As vehicles stay off the road, construction is put on hold, and factories stop production, the levels of microscopic particulate matter, or $PM_{2.5}$, start to drop.

Recent heavy rains in the north and west of the country have also helped the country's pollution levels.

Since the March 25 lockdown that forced 1.3 billion Indians to stay home, air quality in New Delhi, usually the worst in the world, has dropped to "satisfactory" levels. The lockdown order shut down offices, schools, movie theatres, malls, markets and "non-essential" service providers. All modes of public transport such as metro trains, buses, inter-state trains and domestic and international flights for civilian movement have also been stopped, according to Quartz.

The effect of the lockdown has been dramatic in New Delhi. The air pollution levels have dropped 71 per cent in just one week. On March 20, the air had an unhealthy 91 micrograms per cubic meter of $PM_{2.5}$. On March 27, just a couple of days into the lockdown, that level fell to 26 micrograms per cubic metre.

Data from the Central Pollution Control Board of India's Environment Ministry also showed a 71 per cent decrease in nitrogen dioxide levels. Mumbai, Chennai, Kolkata and Bangalore have also recorded a drop in these air pollutants, according to CNN. In Mumbai, the financial capital, air quality levels in March 2019 averaged 153 on the Air Quality Index, which ranks as unhealthy to breathe, according to Reuters. New Delhi averaged 161 last March.

However, it is important to remember that this is a temporary reprieve that will return if industry and vehicular traffic return once the lockdown is over.

Purpose

a. **To investigate the changes in air quality among cities before and during the lockdown period.**
b. **To study the trend of pollutants from 1 Jan to 30 Apr (approximately 120 days) for different cities in India.**
c. **To compare the difference in pollution levels from (2018/19 to 2020) for the post-lockdown period between 25 Mar to 30 Apr.**

Methodology

a. Data collection

Selection of cities

We selected 5 major cities around India based on:

(i) the historical level of air pollution in the city

(ii) reported COVID-19 cases in that city

(iii) the geographical setting and developmental stage

(iv) city lockdown history

(v) availability of air pollution data

The data was sourced from the government websites, Central Pollution Control Board (CPCB). Most of the cities selected for this study are affected heavily by anthropogenic emissions, and a reduction in air pollution is expected in those cities as a result of the lockdown. Our basic focus is on $PM_{2.5}$, SO_2 and NO_2 levels from Delhi, Nagpur, Lucknow, Jaipur and Kolkata. Although we cross-verified the accuracy of the data by looking at multiple media reports, there may be some discrepancies due to any errors in media reporting and differences in time/location.

b. Variable creation

We selected $PM_{2.5}$, NO_2 and SO_2 levels as our variables to investigate the changes in air quality among cities before and during lockdowns.

Variable used	Type of variable
State-wise $PM_{2.5}$ levels	Continuous ratio

State-wise NO_2 levels	Continuous ratio
State-wise SO_2 levels	Continuous ratio

c. Analytic method

Analysis of variance (ANOVA) is used to analyze the differences among group means of NO_2 levels in a sample for the post-lockdown period between 2018, 2019 and 2020 for the mentioned states.

Assumptions

- Each group sample is drawn from a normally distributed population
- All populations have a common variance
- All samples are drawn independently of each other
- Within each sample, the observations are sampled randomly and independently of each other
- Factor effects are additive

Student's t-test is used to determine if the means of the NO_2 levels for the years 2018-19 and 2019-20 are significantly different from each other.

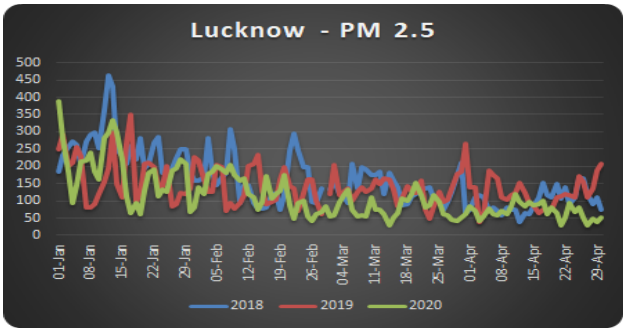
Assumptions

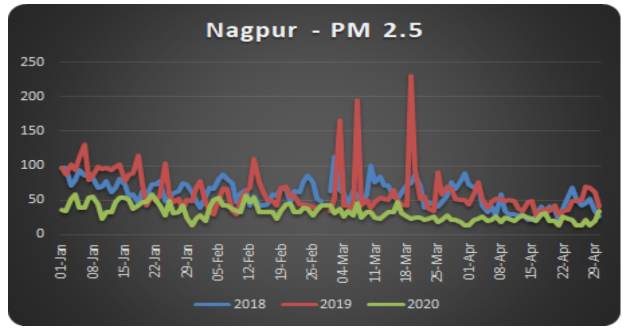
- Assumption of Independence: The should be two independent, categorical groups that represent the independent variable.
- Assumption of normality: The dependent variable should be approximately normally distributed. The dependent variable should also be measured on a continuous scale.

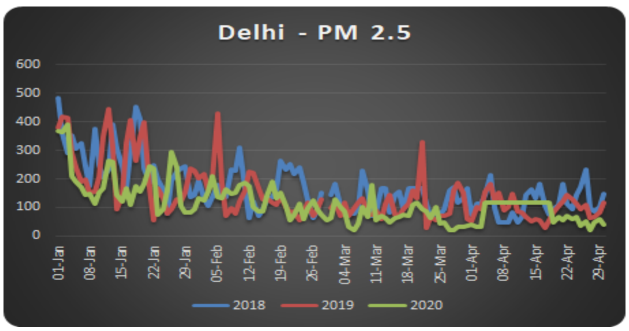
- Assumption of Homogeneity of Variance: The variances of the dependent variable should be equal.

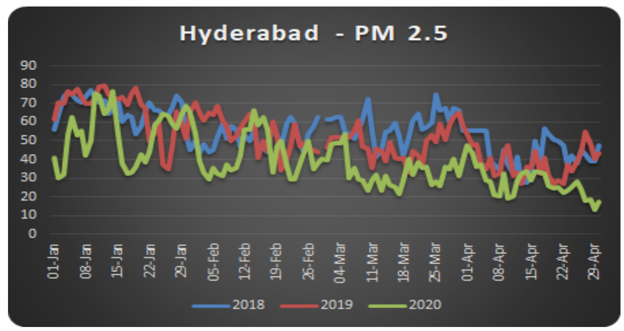
Results and Discussion

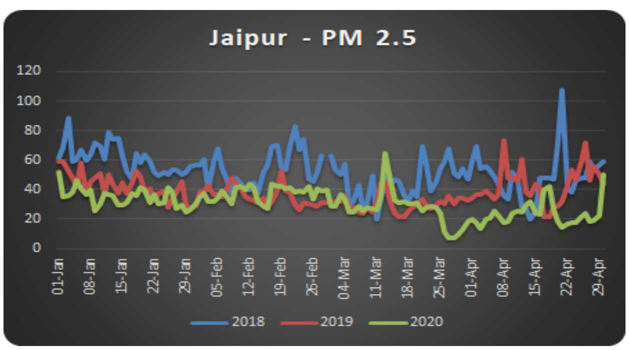
Average daily $PM_{2.5}$ emissions from Jan to Mar in micrograms per cubic metre





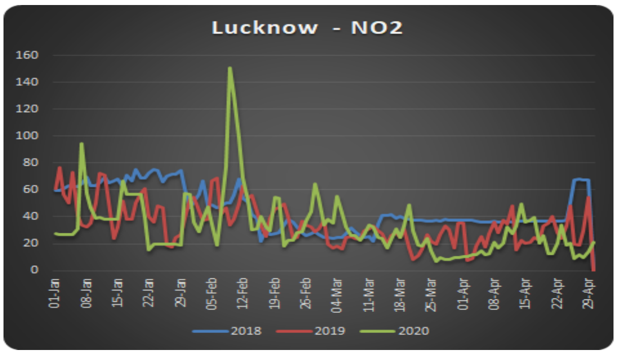


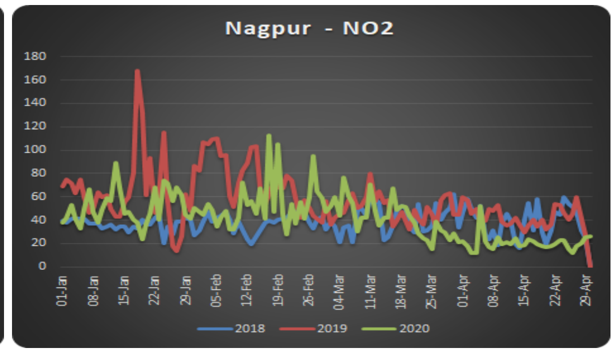


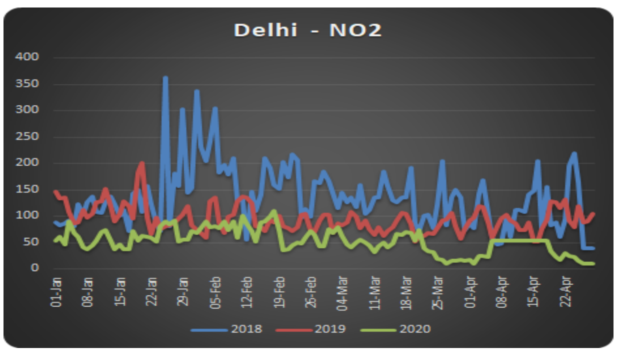


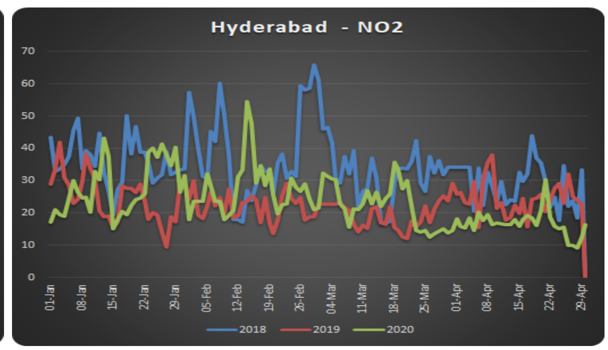
Maximum decline in the mean monthly concentration of $PM_{2.5}$ in January was observed in Nagpur (-47.6%) followed by Delhi (-22.62%), Hyderabad (-19.48%) and Jaipur (-17.88%) whereas Lucknow (+5%) recorded an increase. In February Nagpur (-28.11%), Hyderabad (-21.76%) and Delhi (-12.85%) observed a strong decline whereas Lucknow (-8.63%) showed a marginal decline and Jaipur (+5.22%) recorded an increase. A decline was observed in Nagpur (-57.03%) followed by Lucknow (-40.25%), Delhi (-36.34%), Hyderabad (-30.92%) and Jaipur (-10.24%) in March. A consistent decline was recorded in April in all five cities; Jaipur (-82.48%), Nagpur (-53.32%), Lucknow (-42.36%), Delhi (-30.64%) and Hyderabad (-28.94%).

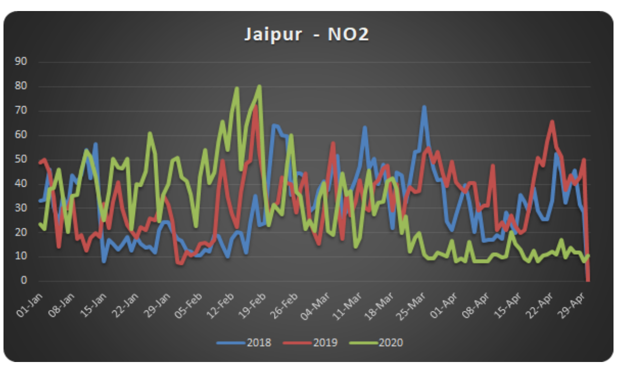
Average daily NO_2 emissions from Jan to Mar in micrograms per cubic metre





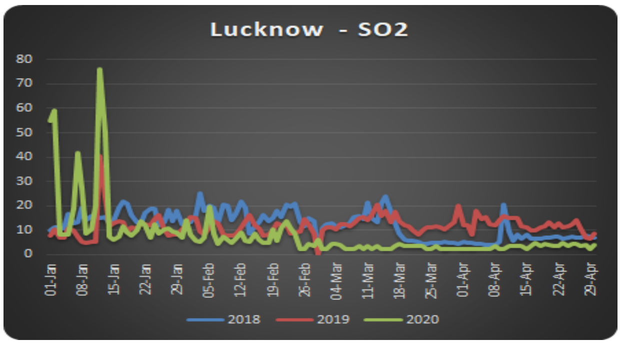


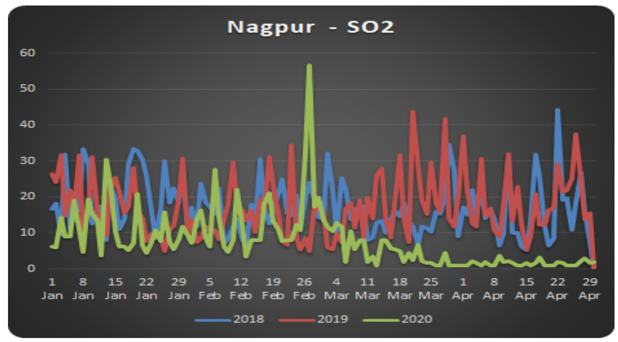


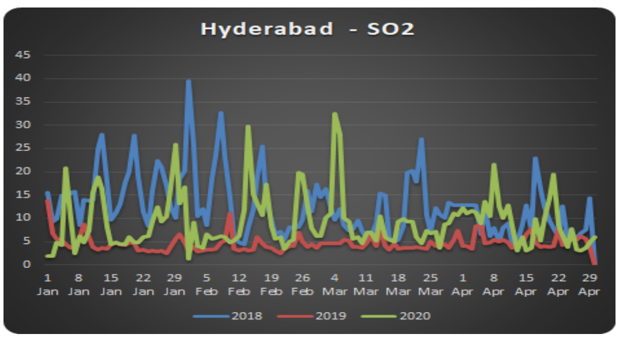


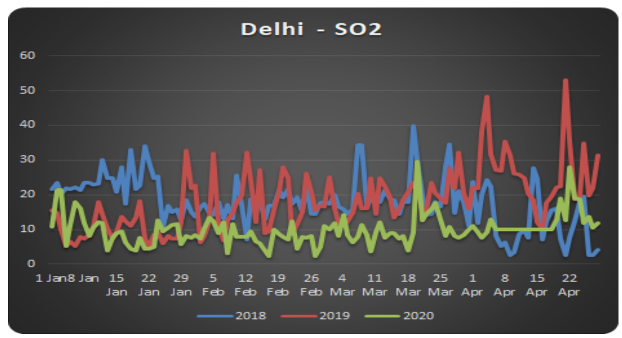
There were mixed trends (an increase in some cities while a decrease in others) in NO_2 for both months of January and February; an increase in two cities Jaipur (+48.43% in January, +47.27% in February), Hyderabad (+12.41% in January, +23.98% in February) while a decrease in two cities; Delhi (-45.43% in January, -23.22% in February), Nagpur (-22.12% in January, -28.78% in February) whereas Lucknow (-16.27% in January, +13.15% in February) peculiar trend. Maximum decline in the mean monthly concentration of NO_2 in March was observed in Delhi (-43.38%) followed by Jaipur (-32.79%) and Nagpur (-15.5%) whereas Hyderabad (+15.97%) and Lucknow (+4.03%) recorded an increase in the emissions. A consistent decline was recorded in April in all five cities; Jaipur (-70.71%) followed by Delhi (-59.76%), Nagpur (-52.75%), Hyderabad (-32.33%) and Lucknow (-27.25%).

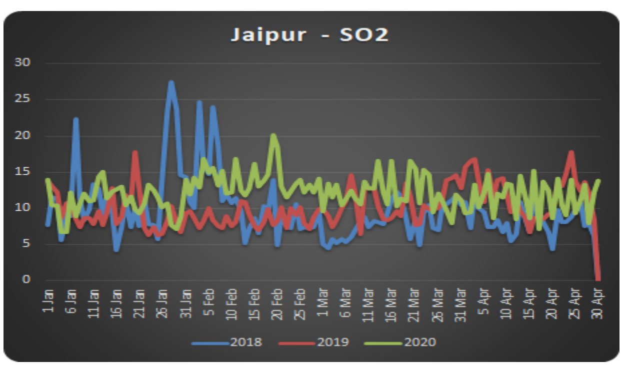
Average daily SO_2 emissions from Jan to Mar in micrograms per cubic metre









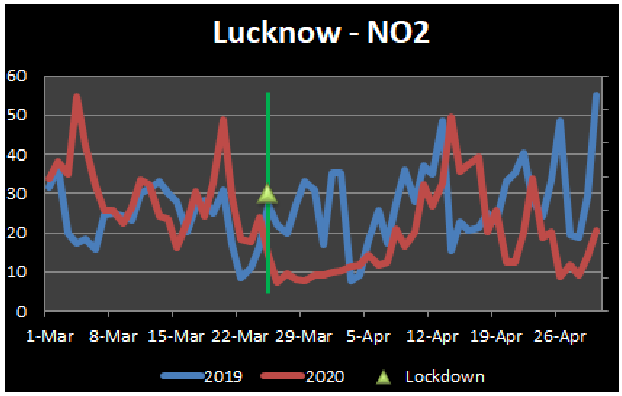


There were mixed trends (increase in some cities while a decrease in others) in SO_2 for both months of January and February; an increase in two cities Jaipur (+14.9% in January, +61.13% in February), Hyderabad (+88.81% in January, +116.35% in February) while a decrease in two cities; Delhi (-13.52% in January, -53.73% in February), Nagpur (-37.67% in January, -1.34% in February) whereas Lucknow (+56.37% in January, -36.8% in February) showed a peculiar trend. Maximum decline in the mean monthly concentration of SO_2 in March was observed in Lucknow (-75%) followed by Nagpur (-69.95%) and Delhi (-45.77%) whereas Hyderabad (+103.87%) and Jaipur (+14.51%) recorded an increase in the emissions. In April Nagpur (-90.6%) followed by Lucknow (-71.8%) and Delhi (-54.73%)

observed a decreasing trend. Jaipur showed a marginal decline (-6.12%) whereas Hyderabad (+66.93%) recorded an increase in emissions.

State-wise NO_2 emissions during the post-lockdown period

Lucknow (UP)



ANOVA: Single Factor

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9170.148047	2	4585.074023	43.20013801	1.64154E-14	3.080386863
Within Groups	11462.64844	108	106.1356337			
Total	20632.79649	110				

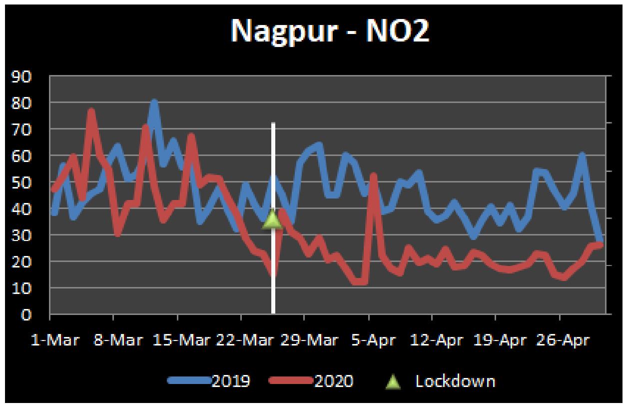
T-test: Two-Sample Assuming Equal Variances

	2018	*2020*
Mean	40.72513514	18.55837838
Variance	97.15429234	113.6620806
Observations	37	37
Pooled Variance	105.4081865	
Hypothesized Mean Difference	0	
df	72	
t Stat	9.286474042	
P(T<=t) one-tail	3.06543E-14	
t Critical one-tail	1.666293696	
P(T<=t) two-tail	6.13085E-14	
t Critical two-tail	1.993463567	

	2019	*2020*
Mean	27.84205405	18.55837838
Variance	107.5905281	113.6620806
Observations	37	37
Pooled Variance	110.6263044	
Hypothesized Mean Difference	0	
df	72	
t Stat	3.796440712	
P(T<=t) one-tail	0.00015177	
t Critical one-tail	1.666293696	
P(T<=t) two-tail	0.00030354	
t Critical two-tail	1.993463567	

There was a statistically significant difference between the years 2018, 2019 and 2020 in the daily NO_2 concentration records for Lucknow after the lockdown was imposed as determined by one-way ANOVA ($F = 43.2001$, $p \approx 0$). Based on the t-test table for years 2018 & 2020 (p-value≈0) and 2019 & 2020 (p-value≈0) we conclude the difference between the two means in both the tables is statistically significant. By comparing the means, we can say that the mean concentration of NO_2 for 2020 is significantly less than that of 2018/2019.

Nagpur (Maharastra)



ANOVA: Single Factor

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	11220.27945	2	5610.139723	54.48338354	4.36163E-17	3.080386863
Within Groups	11120.73169	108	102.9697379			
Total	22341.01114	110				

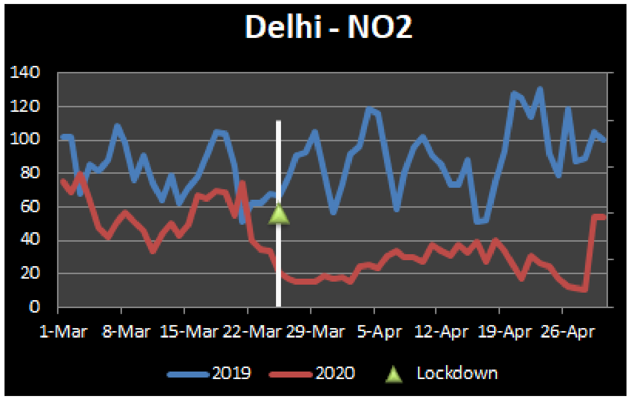
T-test: Two-Sample Assuming Equal Variances

	2018	*2020*
Mean	40.39297297	21.54594595
Variance	165.5304715	55.95747477
Observations	37	37
Pooled Variance	110.7439731	
Hypothesized Mean Difference	0	
df	72	
t Stat	7.703155543	
P(T<=t) one-tail	2.74315E-11	
t Critical one-tail	1.666293696	
P(T<=t) two-tail	5.48629E-11	
t Critical two-tail	1.993463567	

	2019	*2020*
Mean	44.69783784	21.54594595
Variance	87.42126742	55.95747477
Observations	37	37
Pooled Variance	71.6893711	
Hypothesized Mean Difference	0	
df	72	
t Stat	11.76101936	
P(T<=t) one-tail	9.97425E-19	
t Critical one-tail	1.666293696	
P(T<=t) two-tail	1.99485E-18	
t Critical two-tail	1.993463567	

There was a statistically significant difference between the years 2018, 2019 and 2020 in the daily NO_2 concentration records for Nagpur after the lockdown was imposed as determined by one-way ANOVA ($F = 54.48$, $p \approx 0$). Based on the t-test table for years 2018 & 2020 (p-value≈0) and 2019 & 2020 (p-value≈0) we conclude the difference between the two means in both the tables is statistically significant. By comparing the means, we can say that the mean concentration of NO_2 for 2020 is significantly less than that of 2018/2019.

Delhi



ANOVA: Single Factor

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	114925.3045	2	57462.65226	52.42052346	1.22996E-16	3.080386863
Within Groups	118388.1052	108	1096.186159			
Total	233313.4097	110				

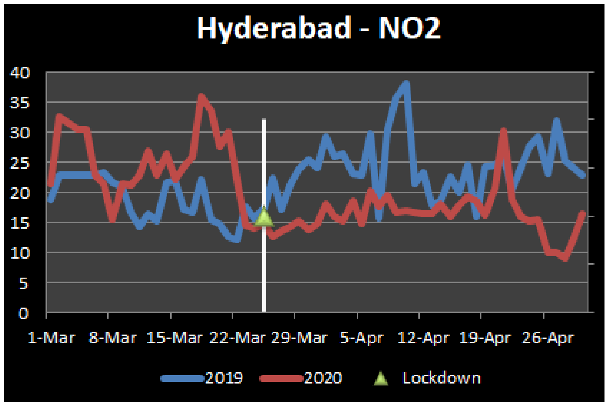
T-test: Two-Sample Assuming Equal Variances

	2018	*2020*
Mean	109.0189189	33.38175676
Variance	2560.59946	309.7012534
Observations	37	37
Pooled Variance	1435.150357	
Hypothesized Mean Difference	0	
df	72	
t Stat	8.587611496	
P(T<=t) one-tail	6.1303E-13	
t Critical one-tail	1.666293696	
P(T<=t) two-tail	1.22606E-12	
t Critical two-tail	1.993463567	

	2019	*2020*
Mean	90.39405405	33.38175676
Variance	418.2577637	309.7012534
Observations	37	37
Pooled Variance	363.9795085	
Hypothesized Mean Difference	0	
df	72	
t Stat	12.8533383	
P(T<=t) one-tail	1.2766E-20	
t Critical one-tail	1.666293696	
P(T<=t) two-tail	2.55321E-20	
t Critical two-tail	1.993463567	

There was a statistically significant difference between the years 2018, 2019 and 2020 in the daily NO_2 concentration records for Delhi after the lockdown was imposed as determined by one-way ANOVA ($F = 52.42$, $p \approx 0$). Based on the t-test table for the years 2018 & 2020 (p-value≈0) and 2019 & 2020 (p-value≈0), we conclude the difference between the two means in both tables is statistically significant. By comparing the means, we can say that the mean concentration of NO_2 for 2020 is significantly less than that of 2018/2019.

Hyderabad (Telangana)



ANOVA: Single Factor

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3406.558501	2	1703.27925	67.68560592	8.83783E-20	3.080386863
Within Groups	2717.773691	108	25.16457122			
Total	6124.332192	110				

T-test: Two-Sample Assuming Equal Variances

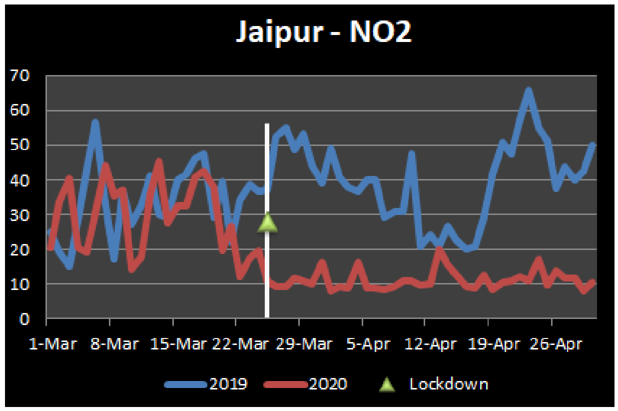
	2018	*2020*
Mean	29.54945455	16.56060606
Variance	39.95464357	13.48703087
Observations	33	33
Pooled Variance	26.72083722	
Hypothesized Mean Difference	0	
df	64	
t Stat	10.2067527	
P(T<=t) one-tail	2.3406E-15	
t Critical one-tail	1.669013025	
P(T<=t) two-tail	4.6812E-15	
t Critical two-tail	1.997729654	

	2019	*2020*
Mean	24.16810811	16.56060606
Variance	24.90537132	13.48703087
Observations	37	33
Pooled Variance	19.53203464	
Hypothesized Mean Difference	0	
df	68	
t Stat	7.189143409	
P(T<=t) one-tail	3.23356E-10	
t Critical one-tail	1.667572281	
P(T<=t) two-tail	6.46712E-10	
t Critical two-tail	1.995468931	

There was a statistically significant difference between the years 2018, 2019 and 2020 in the daily NO_2 concentration records for Hyderabad after the lockdown was imposed as determined by one-way ANOVA (F = 67.68, p≈0). Based on the t-test table for the years 2018 & 2020 (p-value≈0) and 2019 & 2020 (p-value≈0), we conclude the difference between the two means in both tables is statistically significant.

By comparing the means, we can say that the mean concentration of NO_2 for 2020 is significantly less than that of 2018/2019.

Jaipur (Rajasthan)



ANOVA: Single Factor

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	16772.13419	2	8386.067093	82.33133134	1.91028E-22	3.080386863
Within Groups	11000.61461	108	101.8575426			
Total	27772.74879	110				

T-test: Two-Sample Assuming Equal Variances

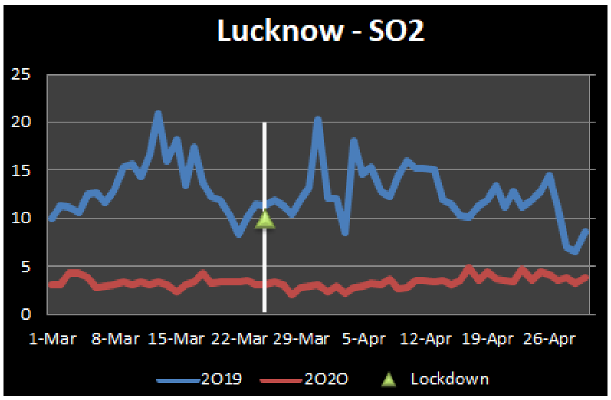
	2018	*2020*
Mean	32.99540541	11.19242424
Variance	158.04127	8.419581439
Observations	37	33
Pooled Variance	87.6310636	
Hypothesized Mean Difference	0	
df	68	
t Stat	9.727374808	
P(T<=t) one-tail	8.34686E-15	
t Critical one-tail	1.667572281	
P(T<=t) two-tail	1.66937E-14	
t Critical two-tail	1.995468931	

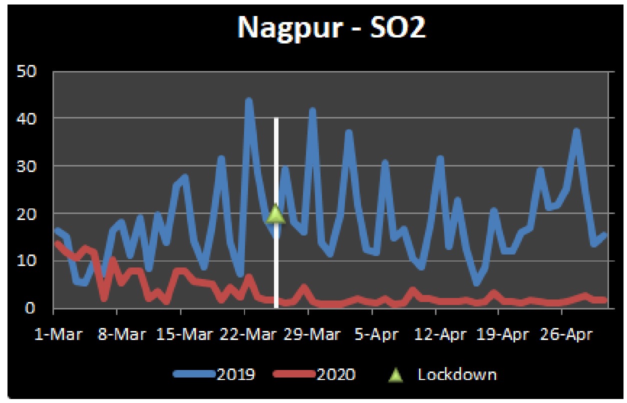
	2019	*2020*
Mean	39.97675676	11.19242424
Variance	139.7640559	8.419581439
Observations	37	33
Pooled Variance	77.95489142	
Hypothesized Mean Difference	0	
df	68	
t Stat	13.61580395	
P(T<=t) one-tail	2.11406E-21	
t Critical one-tail	1.667572281	
P(T<=t) two-tail	4.22812E-21	
t Critical two-tail	1.995468931	

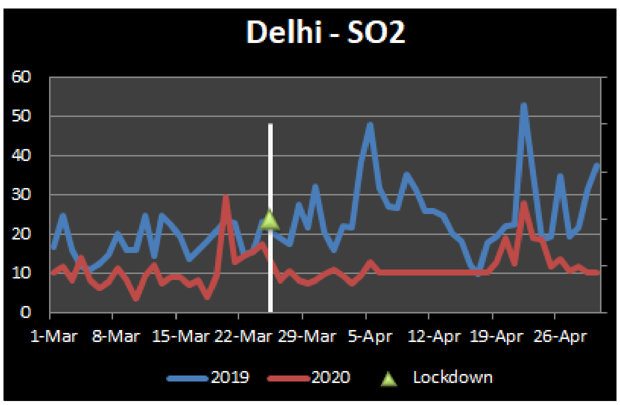
There was a statistically significant difference between the years 2018, 2019 and 2020 in the daily NO_2 concentration records for Jaipur after the lockdown was imposed as determined by one-way ANOVA ($F = 82.33$, $p \approx 0$). Based on the t-test table for the years 2018 & 2020 (p-value≈0) and 2019 & 2020 (p-value≈0), we conclude the difference between the two means in both tables is statistically significant.

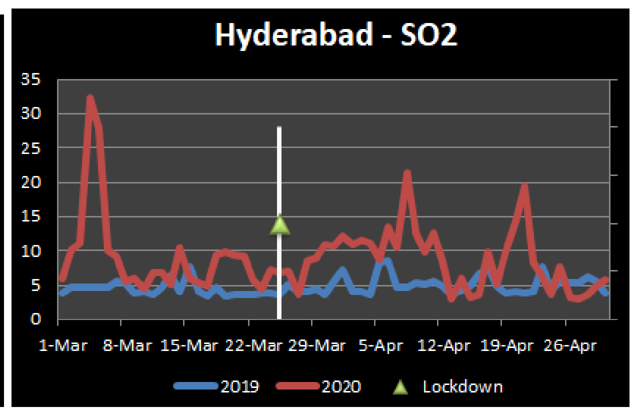
By comparing the means, we can say that the mean concentration of NO_2 for 2020 is significantly less than that of 2018/2019.

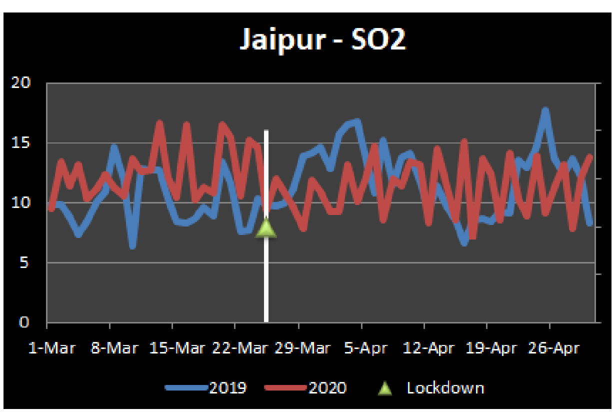
State-wise SO_2 emissions during the post-lockdown period











Similarly, we observe a statistically significant difference between the years 2018, 2019 and 2020 in the daily SO_2 concentration records for almost all cities after the lockdown was imposed except Hyderabad and Jaipur as determined by one-way ANOVA. Some of the major sources of SO_2 are big coal-fired power plants that might not have been shut down during the lockdown and hence SO_2 concentrations in the cities would not have gone down.

Conclusion

The entire Planet has changed within a period of a few months due to the pandemic COVID-19. Industries have been closed down. Transport sectors are dwindling due to a complete shutdown of domestic and International flights. Tourism activities have ceased and hence all hotels, tourism units, homestays and other recreational activities (like water sports, amusement parks *etc*.) related to tourism have been stopped. The running of trains, buses and passenger vessels has also ceased. All these have significantly reduced the consumption of fossil fuels and subsequently, emissions of various air pollutants have also touched the trough.

As industries, transport networks, recreational units, offices and businesses have closed down, it has brought a sudden drop in nitrogen dioxide emissions into the atmosphere.

In the present study, a significantly decreased percentage of $PM_{2.5}$, NO_2 and SO_2 can be seen in the major cities. ANOVA showed significant variations in NO_2 levels between the years. Later on, using the Student's t-test we observed a statistically significant decrease during the post-lockdown period. The variation in NO_2 level between years can be substantiated by the COVID-19 pandemic, but the apparent variation between sites is attributed to existing vegetation in the site along with anthropogenic activities of various dimensions.

Though the reduction is expected to be short-lived, it provides us with encouraging evidence that a swift and widespread implementation of air pollution measures, as proposed by several scientific studies, can result in immediate air quality benefits. The importance of continuing to enforce existing air pollution control regulations to protect human health both during and after the COVID-19 crisis cannot be and should not be ignored. It is worth noting that enormous damage has been caused by air pollution globally especially in developing countries for at least the last two decades which demands immediate action. While the enormous outpouring of support and global solidarity was seen that spurs numerous actions to mitigate, control, and eradicate the COVID-19 pandemic, it is equally essential to show a similar level of urgency, solidarity and actions to address the great chronic environmental disasters of air pollution, a silent killer of approximately seven million people worldwide every year.

References

- https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing/caaqm-comparison-data
- https://en.m.wikipedia.org/wiki/COVID-19_pandemic_in_India
- https://en.m.wikipedia.org/wiki/COVID-19_pandemic
- https://en.m.wikipedia.org/wiki/Impact_of_the_COVID-19_pandemic_on_the_environment
- https://www.ecowatch.com/india-air-pollution-coronavirus-2645617908.html