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SHORT COMMUNICATION

Surface Ozone and its Precursor Gases Concentrations during COVID-19 Lockdown and Pre-Lockdown Periods in Hyderabad City, India

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Abstract

Drastic measures such as lockdown imposed in the countries worldwide to control the extent of *COVID-19* have influenced environmental parameters substantially. The aim of the present study was to investigate the impact of lockdown on the air quality in Hyderabad city by comparing the pollutants concentration during lockdown and pre-lockdown periods. A comparative study was also made on the pollutant concentrations observed during the pre-lockdown (1st February – 23rd March 2020) and lockdown period (24th March - 30th April 2020) to those of the pollutants in the previous years (2018 and 2019). The Pearson correlation coefficient was employed to correlate the ozone (O_3) concentration with other pollutants. Carbon monoxide (CO), nitrogen oxides (NO_X) and O_3 were monitored along with meteorological parameters like temperature, relative humidity and solar radiation. It was observed that the O_3 concentration increased from 26 ppb (by volume) to 56.4 ppb during pre-lockdown and lockdown period, respectively, due to the decrease in CO and NO_X concentration. The concentration of $NO_{2,}$ NO and CO were also reduced during the lockdown period by 33.7%, 53.8% and 27.25%, respectively. To identify the statistical significance of the parameters, analysis of variance (ANOVA) was used. The present study provides new insights on the ambient air pollution in terms of the aforesaid parameters and could pave the way for regulatory authorities to implement control measures to curb the air pollution.

Highlights

- COVID-19 lockdown improved the air quality by the reduction in air pollutants leading to increased ozone concentration.
- Pearson model was used to correlate the ozone (O_3) with oxides of nitrogen (NO_X), CO and other meteorological parameters.
- NO_X and carbon monoxide (CO) concentrations were reduced by 33.7 % and 27.25 %, respectively, due to COVID lockdown.

Keywords *COVID-19* · Lockdown · Pre-lockdown · Ozone · Precursor gases

1 Introduction

COVID-19, a deadly pandemic has shattered the lives of the entire world population by infecting millions of people across the globe. An unknown virus causing severe pneumonia, leading in some cases to death, was detected in the city of Wuhan in China in December 2019 and was spread rapidly across the globe, infecting people worldwide and claiming numerous lives, with 80% of cases occurring in Europe and the United States. *COVID-19* has impacted all the developed, under-developed and the developing countries in terms of economy, resources, and loss of lives (Sarkodie and Owusu 2020).

Although the pandemic has disrupted human life, the environment seems to have been benefitted. For instance, the polluted environment in countries like India has been greatly benefitted because the nation-wide lockdown imposed from 24th March to 31st May 2020 which led to the reduction of pollution levels in the atmosphere, due to the halt of vehicle traffic and industrial operations (Tobias et al. 2020). The gaseous emissions from vehicles and industries are the two major reasons for the extreme atmospheric pollution levels in India. During nation-wide lockdown, the social and print media were flooded with photographs of blue skies and clearer water bodies. Several cities in India recorded over 60% drop in air pollution levels and some even claimed that air pollution was no longer a real concern during the lockdown (Levels 2020). Monitoring of atmospheric data in China showed that the observed pollutants were reduced by approximately 20–30% in the month of February 2020 (Zambrano-Monserrate et al. 2020). Amongst many other sectors, the transport sector was greatly affected during the lockdown. Road and air transport came to stand still (WHO 2020) as people were not allowed to travel. According to recent reports, air travel dropped by 96% due to the *COVID-19* pandemic to the lowest recorded level in the past 75 years (Wallace 2020). A cleaner and blue sky has been greeted by citizens of the Telangana state in India particularly in the Hyderabad city. Perhaps for the first time in recent history, the pollution levels observed in various weather monitoring stations in the city were way below the standards set by the government of India (The Hindu 2020).

The quality of air is adversely hit by the aerosol released by a variety of chemicals from agriculture, manufacturing industries, combustion engines and garbage burning, which are typically assessed by measuring the concentration of atmospheric pollutants like ozone (O_3), nitrogen oxides (NO_X), carbon monoxide(CO), sulphur dioxide (SO_2) volatile organic compounds (VOCs) and particulate matter (PM_{10}). Anthropogenic troposphericO_3 is a secondary air pollutant which consists one of the greenhouse gases responsible for global warming (Swamy et al. 2012). Ozone is formed through photochemical reactions of primary pollutants like NO_X, CO, volatile organic compounds (VOCs) and sulphur oxides (SO_X) in the presence of solar radiation (SR) and suitable temperature (Temp) conditions. These precursor pollutants are emitted either directly by vehicles and industries, or results after incomplete combustion of fossil fuels and biomass burning in the agriculture fields (Shavrina et al. 2010).

Nitrogen dioxide (NO_2) is a highly reactive pollutant that is produced mainly from fossil fuel combustion, primarily from vehicle traffic. NO_2 may cause bronchial hyper-responsiveness, cellular inflammation and respiratory problems (He et al. 2020). In urban areas worldwide, NO_2 is the leading cause of childhood asthma (Achakulwisut et al. 2019). One of the primary pernicious and inevitable consequence of urbanization and industrial activities is the generation of air pollutants. Prolonged exposure to SO_2 and NO_2 may results in respiratory organ damage and contribute to the emergence of respiratory disease and carcinoma (Khaniabadi et al. 2017). Similarly, chronic exposure to SO_2, CO and O_3 can harm the human respiratory system which may give breathing problems including death in some cases (Chen et al. 2007; Brown 2009).

COVID-19 has a significant negative effect on human health and the global economy, but due to restricted social and economic activities, it has also had a positive impact on the reduction of air pollution parameters (Dutheil et al. 2020; Bauwens et al. 2020). According to Copernicus Atmosphere Monitoring Service (CAMS 2020) information on particulate matter ($PM_{2.5}$), 20–30% reduction was observed during February 2020 compared with monthly average of February 2017, 2018 and 2019 in China. Additionally, PM_{10} and NO_2 reductions of 31% and 51%, respectively, were observed in lockdown period compared with pre-lockdown in Barcelona (Tobias et al. 2020). Sharma et al. (2020) also observed different cities in India, concluding that the average of CO and NO_2 $PM_{2.5}$ and PM_{10}, was decreased by 10, 18, 43 and 31%, respectively, and a 17% increase in O_3 concentration was observed during lockdown compared with pre-lockdown.

Therefore, the *COVID-19* lockdown provides a unique opportunity to carry out research on the impact of anthropogenic emissions on nationwide atmospheric air quality. Hence, a quantitative assessment of air pollution needs to be carried out to understand the impact of lockdown measures on air quality, particularly when there is a need to implement control measures. The present study aimed to investigate the impact of lockdown on atmospheric air quality in Hyderabad city. This was studied by comparing the levels of $O_{3,}$ which is impacted due to the precursor CO, NO and NO_X gases, during lockdown and pre-lockdown periods. These pollutants were measured at the Tata Institute of Fundamental Research - National Balloon Facility (TIFR-NBF; 17.47°N, 78.58°E; altitude 536 m above mean sea level) located in Hyderabad, Telangana. In addition, the study aimed the pollution levels by comparing data for the period 24th March – 30th April 2020 with the previous two years (2018 and 2019).

2 Materials and Methods

2.1 Study Region

The current study was carried out at the Tata Institute of Fundamental Research - National Balloon Facility (TIFR-NBF; 17.47° N, 78.58° E; altitude 536 m above mean sea level) located in Hyderabad, Telangana, metropolitan region and capital city. Hyderabad is the 5th largest city in India, with a population of more than 8 million (Census 2020), along with its twin city of Secunderabad. It is an industrial hub in South-East India, hosting many Special Economic Zone (SEZ) factories for heavy industries, research centres and technology. It is one of the fastest growing areas because of its importance as a major high-tech hub with a population density of ~17,000 people per sq.km. Migration to twin cities has been encouraged by the rapid pace of urbanization with increased economic development, which has led to an increase in personal, public, and 3 to 6 seat car transit vehicles, industrial production and growing pressures on the city's infrastructure. Several industries are located in and around the study area, including power industries, petroleum industries and small-scale chemical / pharmaceutical industries (Swamy et al. 2013; Allu et al. 2020).

2.2 Methodology

An assessment for the air quality status of Hyderabad during the lockdown period from March to May 2020 was studied by comparing with pre-lockdown data. During the study period, the data for NO, NO_2, CO and O_3 were obtained from automatic analyzers from Thermo Fisher Scientific housed at TIFR-NBF. The gas analyzes used for O_3 (Model 49i, Thermo Scientific, USA) works on ultraviolet (UV) light absorption photometry where O_3 molecules absorb UV light at wavelength of 254 nm. The degree to which of the UV light is absorbed is directly related to the concentration of O_3 as defined in the law of Beer-Lambert's (Venkanna et al. 2015). The CO analyzer (Model 48i, Thermo Scientific, USA) operates on the theory of non-dispersive infrared absorption. The NO_X analyzer (Model 42i, Thermo Scientific, USA) is based on the theory of chemi-luminescence, where light intensity is linearly proportional to the NO concentration. Calibration for all analyzers was conducted on weekly basis and the dry air is used for zero calibration. The O_3 analyzer period calibration was performed by using a multi-point, internally assembled O_3 generator. Span calibration for NO_X and CO was performed by using their respective National Institute of Standards and Technology (NIST) traceable standard gases through multi-point calibrator cum dynamic dilutor (Model 146i, Thermo Scientific, USA) (Allu et al. 2020). Monitoring of trace gas samples were collected through gas sample handling system (SHS), and was passed automatically to the analyzers through polytetrafluoroethylene (PTFE) filter paper (47 mm; 0.5 μm) after cooling and de-moisturising the sample. Data was collected with an interval of 5 min and was retrieved using the software Envidas given by Thermo Fisher. 288 samples were recorded per day, the collected data from the analyzers were initially organised in spread sheets as 24-h means. The meteorological parameters are temperature (Temp), relative humidity (RH), wind speed (RH) and wind direction (WD) and were measured by using an automatic weather station (AWS) installed at the site (TIFR–NBF). Solar Radiation (SR) was recorded using Epply model 8–48 pyranometer (Venkanna et al. 2016).

2.3 Pearson Correlation Coefficient

Testing the degree of correlation between two or more variables is one of the most widely used statistical procedures. Pearson correlation coefficient is reported by '*r*' and it is used to determine the strength of linear relationship between two variables (Hashim et al. 2018). In the present study, the Pearson correlation method (Mahato et al. 2020; Waldmann 2019) was applied to determine whether there is a statistically significant positive or negative relationship between ground level O_3 with precursor gases and meteorological parameters during pre-lockdown and lockdown periods using Matlab2019 software.

According to Eq. (1).

$$r_{xy} = \frac{\sum_{i=1}^{n}\left(x_i - \overline{x}\right)\left(y_i - \overline{y}\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - \overline{x}\right)}\sqrt{\sum_{i=1}^{n}\left(y_i - \overline{y}\right)}} \tag{1}$$

where: n is the sample size;

x_i, y_i are the individual sampled points indexed with *i*; $\overline{x}$ is the sample mean.

$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} xi$ **(the sample mean); and analogously for** $\overline{\mathbf{y}}$**.**

and similarly, for y.

2.4 ANOVA Test

ANOVA analysis is to determine the F-value and p value among the group means: for $p > 0.1$, the data is not statistically significant; for $p \leq 0.05$ the data is significant (Ibe et al. 2020). In this study XLSTAT was used for one way-ANOVA, which shows the importance of factors by the response variable means, P and F value for pre-lockdown and lockdown.

3 Results and Discussion

3.1 Concentrations of Major Pollutants in the Pre-Lockdown and Lockdown Periods

After declaration of lockdown starting from 24th March 2020, movement of people and industrial activities has declined, thus, it was anticipated that the pollution levels in the ambient atmosphere would decrease.

The data obtained from the monitoring station during lockdown (24th March 2020 to 30th April 2020) and pre-lockdown period, i.e., from 1st February 2020 to 23rd March 2020 were analyzed separately and the effect of precursor gases on the variation of O_3 pattern was studied. During the above study period the concentrations of CO, NO_2 and NO have shown significant declining trends. CO has shown a maximum concentration of 349.68 ppb by volume during pre-lockdown period which decreased to a minimum of 192.5 ppb during the lockdown period. This can be attributed to less movement of light motor vehicles, motorcycles and heavy-duty vehicles (Fig. 1a, b). It can be observed that the CO concentration was at peak at 11:00 h in the day in all three months.

In case of NO_X emissions, both NO and NO_2 were monitored. It can be observed from Fig. 2a, b that the NO concentration has shown a lower concentration of 3.1 ppb during the pre-lockdown period which continued till first week of April (shown in Fig. 2a) followed by a marginal rise in the concentration. This observation can be attributed to the movement of few vehicles allowed for the transportation of essential goods like medicines, milk and groceries. In the case of NO_2 the concentrations were 25.6 ppb and 6.3 ppb during pre-lockdown and

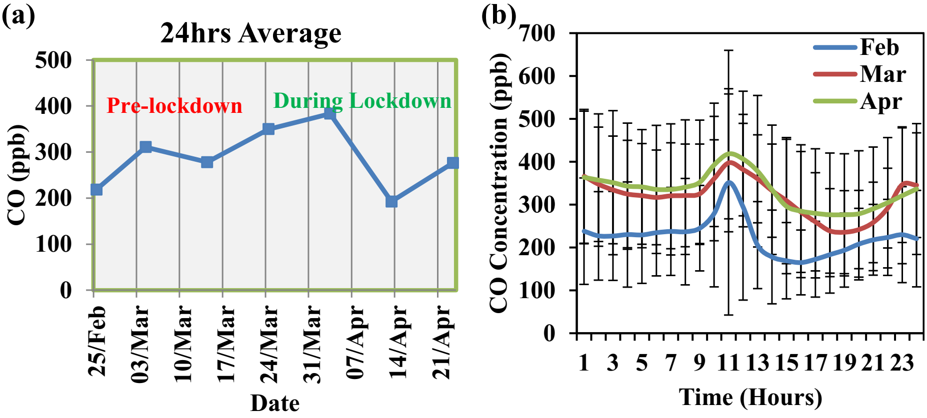


Fig. 1 CO concentration during pre-lockdown and lockdown periods (**a**) 24 h average (**b**) monthly hourly average

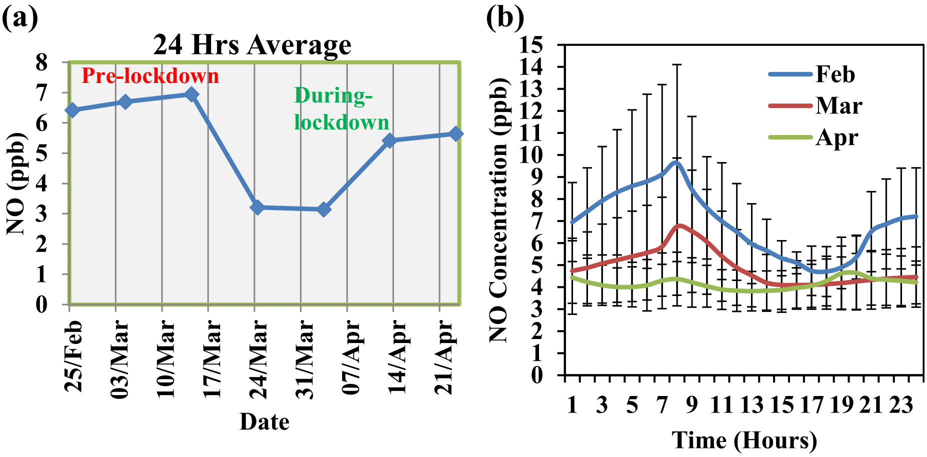


Fig. 2 NO concentration during pre-lockdown and lockdown periods (**a**) 24 h average (**b**) monthly hourly average

lockdown periods, respectively (Fig. 3a, b). The diurnal NO_X plot (Fig. 4a, b) shows a wave-like pattern with raise in NO_X during early morning hours (8:00–9:00 am) and again at night (9:00–10:00 pm). The wave pattern was similar for the study period and the NO_X concentrations were high during pre-lockdown period and were low during the lockdown period, which can be seen clearly in Fig. 4a. NO_X in the form of NO_2 produces O_3 by photolysis during daytime, and NO in NO_X reduce O_3 during night time, which confirms the formation of O_3 by reduction.

O_3 concentrations were compared between 25th February to 30th April 2020. The available data showed a mixed trend which can be observed in Fig. 5a. O_3 concentration marginally decreased from 25th February to 15th March (19.5 ppb to 17.5 ppb) and then increased by more than 50% by attaining a maximum of 48.4 ppb during the lockdown period. This increase in O_3 concentration was primarily due to the down trend in concentrations of NO_X, CO and photochemical titration reaction of NO_X, CO, VOCs and CH_4 with meteorological conditions.

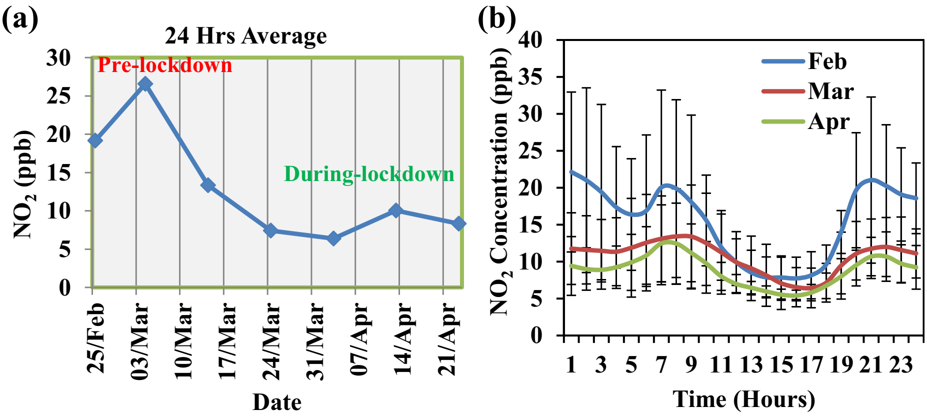


Fig. 3 NO_2 concentration during pre-lockdown and lockdown periods (**a**) 24 h average (**b**) monthly hourly average

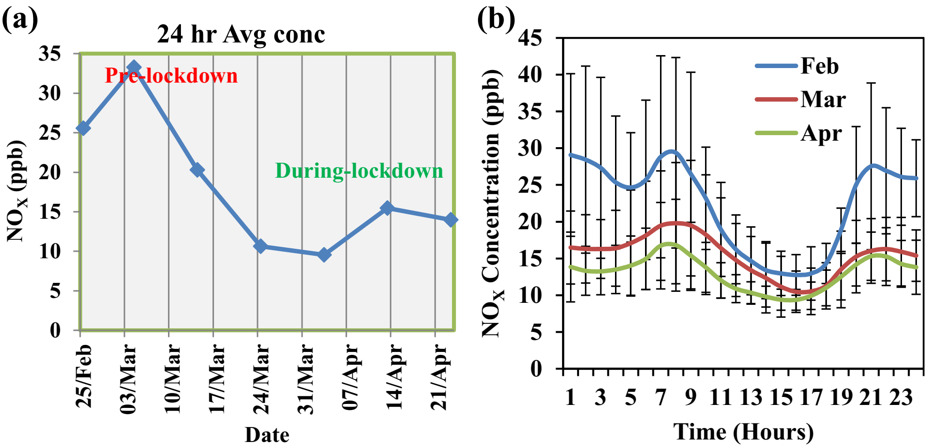


Fig. 4 NO_X concentration during pre-lockdown and lockdown periods (**a**) 24 h average (**b**) monthly hourly average

In Barcelona, Spain around 50% of O_3 concentration was observed during lockdown period due to the titration of NO_2 and decrease of NO_X, (Tobias et al. 2020). The urban area of Brazil recorded 30% increase in O_3 concentration due to drop in NO during the lockdown which led to positive effect on air quality and negative effect on social aspects (Nakada and Urban 2020). Sharma et al. (2020) also observed reduction of NO_2 during lockdown period compared with pre-lockdown. Figure 5b shows that O_3 concentration increased in the early hours of the day dropped at night and attained a peak in the late noon. This increase in O_3 concentration during the noon time in an urban area can be attributed to the photochemical oxidation of the precursor gases like CO, CH_4 and VOCs with sufficient NO_X concentrations. From the above observations, it can be concluded that implementation of lockdown has shown an improvement in the overall air quality.

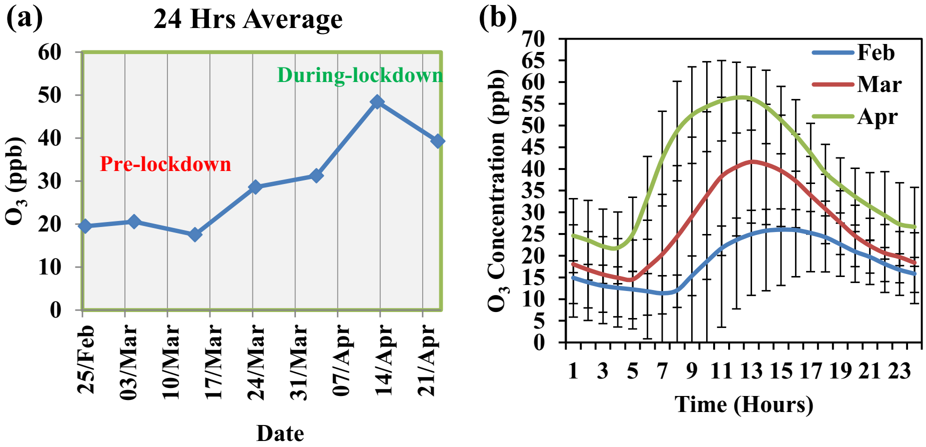


Fig. 5 O_3 concentration during pre-lockdown and lockdown periods (**a**) 24 h average (**b**) monthly hourly average

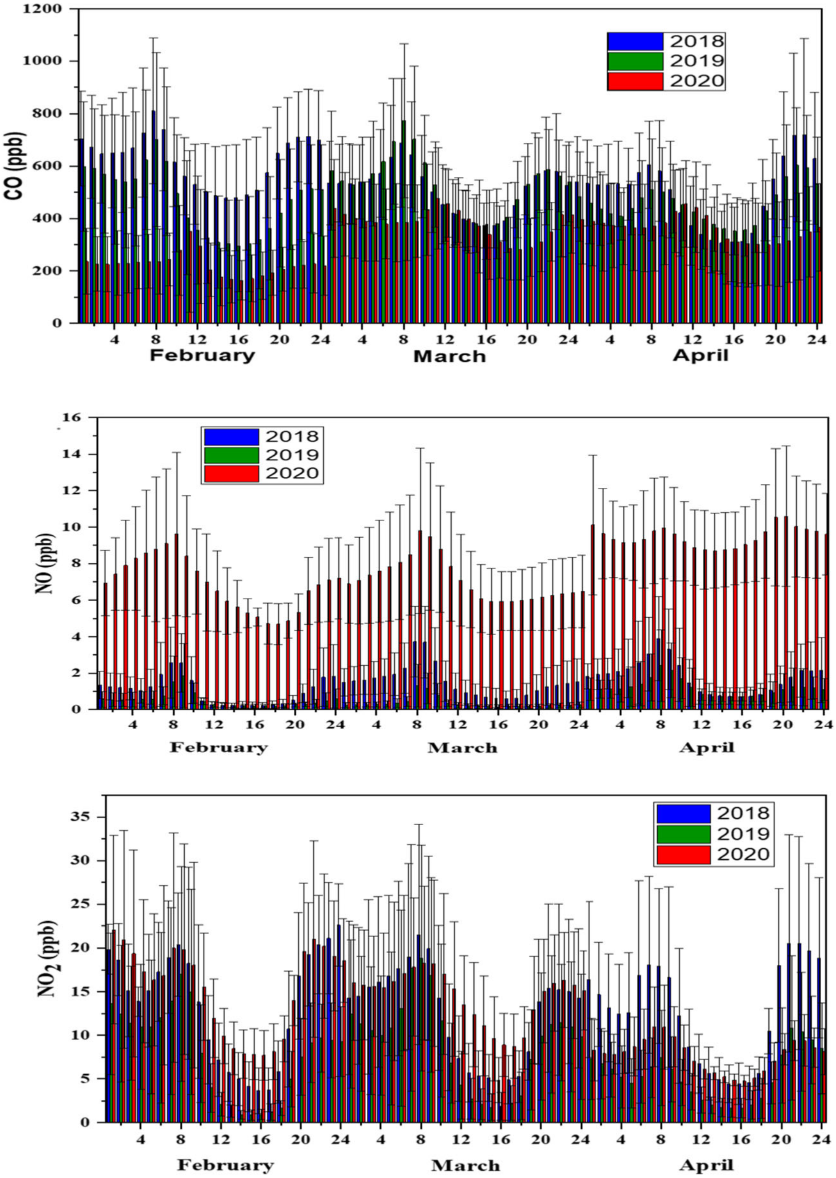
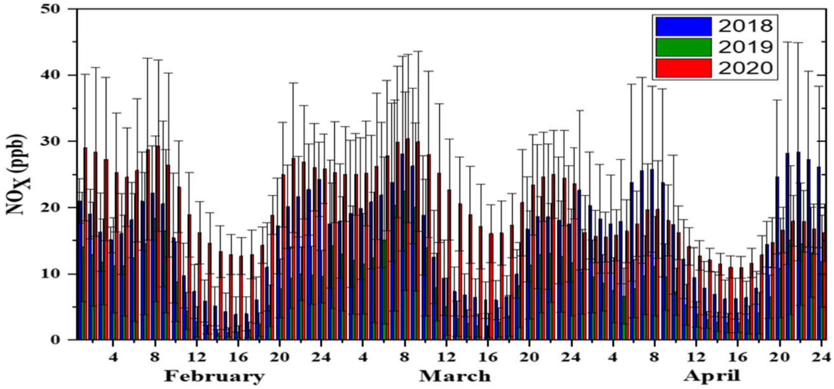


Fig. 6 Trends of diurnal concentrations of pollutants and surface Ozone (O_3) for three months during the years 2018–2020

3.2 Comparison of Precursor Gases Concentration Amidst *COVID-19* Lockdown Period with Previous Two Years 2018–19 in the Same Period

The current year data is also compared with the previous two years data. It can be observed from Fig. 6 that the diurnal concentrations of CO, NO, NO_2 and NO_X pollutants exhibited a reduction in the year 2020 compared to the similar periods in previous years 2018 and 2019. NO_X and CO show a reduction of 27.25% and 83.79%, respectively, whereas the O_3



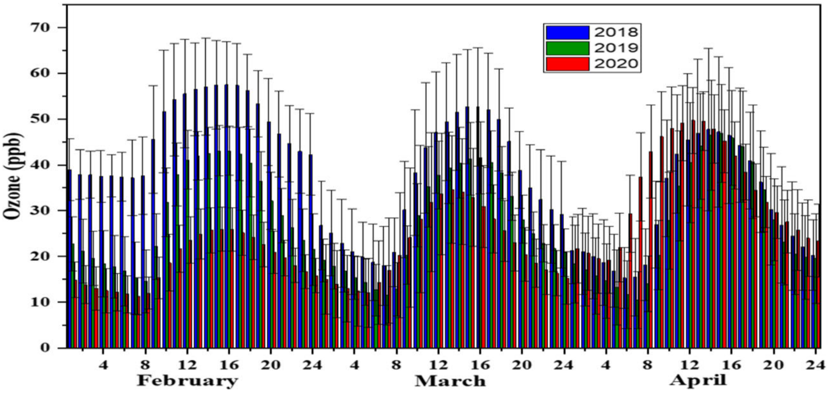


Fig. 6 (continued)

concentration was lightly increased as expected, mostly due to the decrease of the NO$_X$, NO$_2$ and CO concentrations which were observed during the lockdown period; this is probably due to the titration of O$_3$ and inverse variation with NO$_X$ and O$_3$. The NO concentrations were similar during lockdown and pre-lockdown periods due to the lower titration of O$_3$ by NO during the lockdown period. Zambrano-Monserrate et al. (2020) in China also observed increasing trend on O$_3$ during the lockdown period for the month of February 2020 compared with 2019. Statistical inference for the changes in the concentration of major pollutants along with the surface O$_3$ during the lockdown period (i.e., from 24th march to 30th April 2020) in comparison to the previous two years (2018 and 2019) for the same period is summarized in Table 1. It can be noticed (Table 1) that over the previous two years in the said period the concentration of NO$_X$ was substantially high counting to 50.80 ppb (average of the two years 2018 and 2019) in comparison to the current year's average of 39.92 ppb the maximum average concentration of NO$_X$ and CO during 2018 and 2019 were 63.19 and 1831.56 ppb, respectively, which were reduced to 39.92 ppb and 821.27 ppb for the year 2020 (lockdown period), showing that the implementation of lockdown led to substantial improvement of air quality.

Table 1 Average statistical data for the period of 24th March to 30th April during 2018–2020 in ppb

Basic Statistics	2018	2019	Avg of 2018–19	2020	Variation (2020 and avg of 2018–19		Variation (2020 and 2018)	
					Net	%	Net	%
NO	0.79	0.48	0.64	3.96	3.32	83.83	3.17	80.05
NO_2	13.58	6.23	9.94	8.62	−1.32	15.31	–4.96	57.54
NO_X	14.31	6.72	10.51	12.64	2.13	16.85	−1.67	−13.21
CO	452.73	411.01	431.87	337.01	−94.86	–28.14	−115.72	−34.33
O_3	37.17	31.19	34.18	39.16	4.98	12.71	1.99	5.08

3.3 Pearson Correlation Coefficient

The proportion of the O_3 variability based on the precursor gases can be accounted using Pearson statistical method (Hashim et al. 2018). Meteorological interferences mainly due to the transport of the pollutants from the industrial area might have also impacted the results. From the Pearson correlation matrix (Tables 2 and 3), O_3 showed a positive correlation with temperature both in pre-lockdown and during lockdown periods. This is due to the effect of solar radiation in photochemistry (Sillman et al. 1990; Venkanna et al. 2015). Atmospheric RH played a major role in the formation and destruction of O_3 showing a negative correlation. During pre-lockdown period, the r value of the Pearson correlation matrix is −0.97 which can be interpreted as highly correlated when compared with relative humidity during lockdown (−0.59) which is moderately correlated. The precursor CO showed positive correlation with O_3 both in pre-lockdown and lockdown periods. The air pollutants NO, NO_2 and NO_X showed a negative correlation with minor to very high association, which can be seen from the tables during the pre-lockdown and lockdown periods. However, during the pre-lockdown period all the parameters were highly correlated whereas during the lockdown period the correlation is minor to moderate. This trend can be attributed to some exceptions and relaxations for the movement of essential goods given during the last week of the April. This trend is supported by Fig. 5a as well. The above findings indicate that the evaluation of air quality policies in the city of Hyderabad should include analysis of air masses transported from the areas of the industries and impact of NO_X on O_3 levels along with meteorological parameters. Ozone is well correlated with RH, NO, NO_2, NO_X and CO during lockdown (−0.59, −0.37, −0.50, −0.47 and 0.09) compared with pre-lockdown (−0.97, −0.73, −0.87, −0.84 and 0.02), as shown in Fig. 7a, b.

Table 2 Pearson correlation matrix of different variables during pre-lockdown

	O_3	RH	Temp	NO	NO_X	NO_2	CO	SR
O_3	1							
RH	−0.9739	1						
Temp	0.9903	−0.9864	1					
NO	−0.7339	0.8659	−0.7868	1				
NO_X	−0.8762	0.9078	−0.9208	0.7934	1			
NO_2	−0.8498	0.8465	−0.8875	0.6637	0.9816	1		
CO	0.0221	0.1309	−0.0780	0.4430	0.2422	0.1587	1	
SR	0.8129	−0.6805	0.7683	−0.2498	−0.6350	−0.7037	0.4595	1

Table 3 Pearson correlation matrix of different variables during lockdown

	O_3	RH	Temp	NO	NO_X	NO_2	CO	SR
O_3	1							
RH	−0.5944	1						
Temp	0.7345	−0.9702	1					
NO	−0.3743	0.4813	−0.5813	1				
NO_X	−0.5020	0.8762	−0.9027	0.7079	1			
NO_2	−0.4784	0.8867	−0.9018	0.6822	0.9985	1		
CO	0.0955	0.3787	−0.2701	−0.2763	0.2257	0.2576	1	
SR	0.6743	0.1477	0.0187	−0.0136	0.2048	0.2400	0.5696	1

3.4 ANOVA Analysis

The p value in Table 4 shows significant values of NO_X, CO, RH and Temp which are <0.05. Therefore, we found a significant difference in the means of pollutants and null hypothesis was rejected. The alternate hypothesis was accepted, which is in agreement made by Jain and Mandowara (2019). Here, we observed higher F-value (723.68) during lockdown for NO_X due to the decrease in concentration compared with pre-lockdown because of stagnant conditions in Hyderabad. The higher F-value indicates the variance within groups is smaller than the variance between groups.

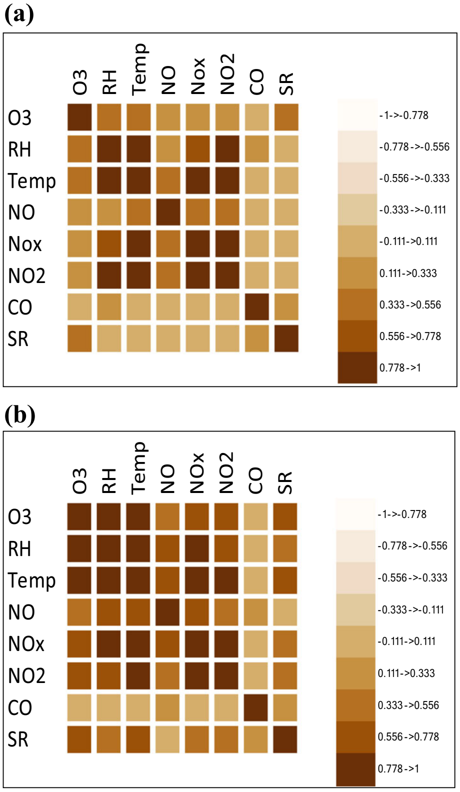


Fig. 7 Image of Pearson correlation matrix (**a**) Lockdown period (**b**) Pre-lockdown period

Table 4 Summary of ANOVA Analysis performed for the data during pre-lockdown and lockdown

	Pre-lockdown				Lockdown			
Parameters	Mean	F	P value	SS	Mean	F	P value	SS
NO_X	16.4	19.55	2.44×10^{-15}	399.46	12.59	723.68	6.02×10^{-40}	13,201.1
CO	261.49	252.65	2.33×10^{-29}	1,512,244	331.72	214.68	1.426×10^{-23}	1,628,576.2
RH	53.22	353.98	6.06×10^{-35}	28,155.78	34.8	6.267	0.014×10^{-5}	320.6
Temp	25.74	45.87	8.24×10^{-10}	766.47	30.59	78.59	2.98×10^{-13}	1325.86

4 Conclusions

The present study investigated the impact of lockdown on the temporal variations in ozone concentration and its precursor gases such as NO, NO_2 and CO, along with local meteorological parameters. The results suggested a positive impact of lockdown on the air quality in Hyderabad city. The confinement of the population, restriction in the movement of both public and private vehicles and economic activities led to the decrease in CO and NO_X levels, thereby increasing the O_3 concentration. The concentrations of CO and NO_X were reduced significantly in 2020 compared to 2018 and 2019, while the concentration of surface O_3 was increased. From Pearson's analysis, we concluded that during the pre-lockdown period all the parameters were highly correlated, whereas during the lockdown period the correlation was minor to moderate. The observations of this study are in agreement with similar observations made across the globe. A significant difference in the mean value of the pollutants was observed and was statistically analysed using one-way ANOVA. Therefore, the present study might be a useful supplement to the regulatory authorities in rethinking the existing regulatory plans in controlling the air pollution in urban areas.

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Code Availability Not applicable.

Authors' Contribution All authors contributed to data collection. Processing of collected data by Sarat Kumar Allu, Rama Krishna Maddala and Shailaja Srinivasan. Statistical analysis was performed by Sarat Kumar Allu and Aparna Reddy. The draft of the manuscript was written by Sarat Kumar Allu and all authors commented on previous version of the manuscript. The draft manuscript was reviewed and edited by Dr. Gangagni Rao Anupoju.

Data Availability My manuscript has no associated data or the data not be deposited.

Declarations

Conflict of Interest Not applicable.

Conflict of Interest The authors declare that they have no conflict of Interest.

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