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Appraisal of Variation in Particulate Pollution Loading with a Change Induced by Anthropogenic Cultural Activity Over a South Indian City-Visakhapatnam

Kavitha Chandu, Dharma Raju Akasapu[1], Samudrala Venkata Jagannadha Kumar[2] and Madhavaprasad Dasari*

Department of Physics, GITAM Institute of Science, GITAM Deemed to be University
Vishakhapatnam, Andhra Pradesh, India
[1]India Meteorological Department, Ministry of Earth Sciences, Hyderabad, Telangana, India
[2]India Meteorological Department, Ministry of Earth Sciences, Vishakhapatnam, Andhra Pradesh, India
✉ madhavaprasaddasari@gmail.com

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Abstract: The study focusses on the variation of air quality assessed from mass concentrations of air pollutants in the year 2020 (particulate matter ($PM_{2.5}$ and PM_{10}), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and ozone (O_3)) amidst COVID–19 restrictions on firework activity during Diwali festive period in Visakhapatnam city. The results are compared with 2018 and 2019. The results indicate that the firework activity affected ambient air quality. The effect is lower in 2020 than in 2018 and even in 2019. In 2019, the effect is lower compared to 2018 due to the washout of pollutants caused by unusual rains on those days.

Key words: Visakhapatnam, air pollution, diwali festival, fireworks, particulate matter, trace gases.

Introduction

The joy during festivals, cultural events and national days is celebrated through cracking fireworks, which impacts ambient air quality in the short term (Ghei et al., 2018; Joshi et al., 2019; Pandey et al., 2016; Parkhi et al., 2016; Pervez et al., 2016; Rastogi et al., 2019; Resmi et al., 2019; Saifi et al., 2018; Sharma et al., 2018). Diwali, the festival of lights is celebrated during October-November every year in India marked by cracking fireworks (Singh et al., 2019; Sharma et al., 2018). The celebration of the festival of lights or 'Diyas' (Diwali) connotes a mythological belief of the triumph of good over evil and the events markedly display the use of pyrotechnics in many parts of the country. The components of fireworks include fuel, oxidisers, binders and metals. Several chemicals are used as fuel (sulphur, charcoal, potassium nitrate), oxidising agents (nitrates, chlorates etc.,) and binders (resin, nitro-cellulose, etc) (Li et al., 2017). Metallic components like iron and lead are used to add colour to the fireworks.

The burning of fireworks release chemicals, smoke, pollutants (carbon dioxide, carbon monoxide, sulphur dioxide, particulate matter and charcoal, etc.,) and generate high levels of noise. Chemicals affect surface water and noise affects wild life. The sounds emanating from exploding crackers may cause hearing loss (Billock et al., 2017). The radiative energy generated by coloured fireworks aid in the photochemical reaction leading to the formation of Ozone (Jana et al., 2014). The sudden and short-term increase in air pollutants can trigger health issues like eye-irritation, allergies,

*Corresponding Author

skin burns, respiratory issues and cardio-vascular problems (Thurston et al., 2016; Zhang et al., 2017). Several studies reported that the release of gases and pollutants during use of fireworks has a short-term effect on air quality and long-term impact on health (Bretón et al., 2020). The emission rate of air pollutants is dependent on the burning rate. Their concentration increases pollutants by 2 to 8 times than normal day concentrations. The pollution concentrations increase suddenly on ground level and people are directly exposed (Singh et al., 2019). These concentrations last for several hours and sometimes a day. The meteorological conditions also play an important role in the concentration and dispersion of pollutants (Watson et al., 1988). Wind speed and its direction, temperature and relative humidity are primary and secondary drivers, respectively. As Diwali is celebrated in autumn/winter season, low temperatures and wind speed build pollutants through horizontal dispersion and shallow boundary layer heights (Bapna et al., 2012; Guttikunda et al., 2011; Hoyos et al., 2020). The higher concentrations are also due to secondary formation during the day (photochemical) and night times.

India is one of the most affected countries due to the COVID–19 pandemic in 2020. Indian government restricted the form of lockdown in the months of March-May 2020 and prohibited several activities like the movement of people, mass transportation, mass congregations besides strict compliance of certain measures and industrial activities. As air pollution can lead to severe and acute respiratory problems in COVID–19 patients, several state governments-imposed ban on the sale and burning of crackers or pyrotechnics. The Indian government gave permission to burst crackers for two hours between 8 and 10 p.m. on Diwali day ie., on 14th November 2020.

Against this backdrop, the present study focusses on the impact of firework activity on concentrations of various air pollutants in the city of Visakhapatnam for the year 2020 and compares the results for the same period in the years 2018 and 2019.

Methodology

The real-time hourly mass concentrations of $PM_{2.5}$, PM_{10}, NO_2, SO_2, ozone and CO were recorded by National air quality index of Central Pollution Control Board compiled for each city under the Ministry of Environment, Forests and Climate Change, India. The instruments measuring the mass concentrations are located in the central point of the city. The data are publicly accessible and data used in this paper are obtained from the website (https://app.cpcbccr.com/AQI_India/). The data relating to meteorological parameters such as maximum temperature, minimum temperature, relative humidity, rainfall, wind speed and wind direction are obtained from India Meteorological Department (IMD).

Study Area

Visakhapatnam (17.6868°N, 83.2185°E) is a major industrial city located on the east coast of India. The major industries such as Hindustan Zinc Limited (HZL), Visakhapatnam Port Trust (VPT), Visakhapatnam Steel Plant (VSP), Hindustan Polymers Limited (HPL), Simhadri Thermal Power Corporation (STPC), Bharat Heavy Plates and Vessels (BHPV) etc., are located at a distance ranging from 5-15 km from the coast. The jurisdictional city area is about 680 km^2 and it is surrounded on three sides by mountains and the Bay of Bengal basin on the east.

Sampling Protocol

The main festival day was on 14th November in 2020, 27th October in 2019 and 7th November in 2018. Thus 6th, 8th November, 2018 and 26th and 28th October 2019 and 13th and 15th November 2020 are considered as pre and post Diwali days for the respective years. Data are collected for 12 hr, an entire day (6 a.m.-6 p.m.) and entire night (6 p.m.-6 a.m.) and 24 hrs taking mean values of pollutants.

Meteorological Parameters

Urban air quality over tropical oceanic areas is due to the transport of pollutants from the Indian subcontinent to the adjoining marine regions by north-easterly and north-westerly winds. During the study period, the variations in meteorological parameters-temperature, relative humidity, wind speed are shown in Table 1. The primary drivers of wind speed and direction are represented in the form of wind rise**.** Wind rise depict and describe the prevalent wind direction and speed graphically. The visualisation in the form of a wind rise gives an instantaneous idea of the bearing and direction from which wind approaches a station during a particular time or season. The wind speed and direction also give us a fleeting glimpse of the ventilation potential of the air, pollution dispersal and also the (in)stability of the

Table 1: Meteorological parameters

Meteorological parameter	*2018*			*2019*			*2020*		
	Pre	*Diwali*	*Post*	*Pre*	*Diwali*	*Post*	*Pre*	*Diwali*	*Post*
Minimum Temperature (ºC)	24.0	23.6	25.6	25.8	25.7	26.2	24.2	25.6	25.6
Maximum Temperature (ºC)	33.0	33.0	32.7	31.4	32.3	32.0	32.0	31.9	31.4
Relative Humidity (%)	79	73	74	78	87	86	56	61	73
Rainfall (mm)	0	0	0	**1.2**	**0**	**12.2**	0	0	0
Average wind speed (km/hr)	3	3	4	4	6	8	10	13	12

Source: India Meteorological Department (IMD).

atmosphere. Wind roses for pre, during and post-Diwali over Visakhapatnam in 2018, 2019 and 2020 are shown in Figure 1. The diurnal variations of temperature and humidity are dissimilar for the study period.

Results and Discussion

The atmospheric stability following conducive ambient conditions like surface inversion or isothermal conditions, winds, rainfall is noteworthy to study as the winds determine the pollution dispersal capacity or the plume dispersion potential; surface inversion or isotherm aids the stagnation of the pollutants hovering in the atmospheric boundary layer; and precipitation dictates washout of the chemicals suspended in the air or spread across lower levels of the atmosphere to reach the ground as a surface pollutant or reach a water source as a potential water pollutant.

From Table 1, it is evident that the rainfall in 2019 and stronger average wind in 2020 are factors that work in wash out the pollutants and in the dispersal of these suspended micro/fine/ultra-fine particles in the years 2019 and 2020, respectively.

It is also apparent from the wind rose diagrams in Figure 1 that the prevailing wind directions on Diwali day in 2018 and 2019 are north-westerly (with a wind speed of 6 to 8 and 8 to 10 kmph) and easterly (wind speed of 8 to 10 kmph) and hence the pollutants should disperse to south-east and western parts of the city. On Diwali day of 2020, the wind direction was predominantly northerly (with a peak wind speed of 18 to 20 kmph) followed by north-easterly (maximum wind speed of 22 to 24 kmph) which abet a southward and south-westward migration of the pollutants. The post-Diwali day winds in 2018 are dominated by north-easterlies (with a wind speed of 8 to 10 kmph)

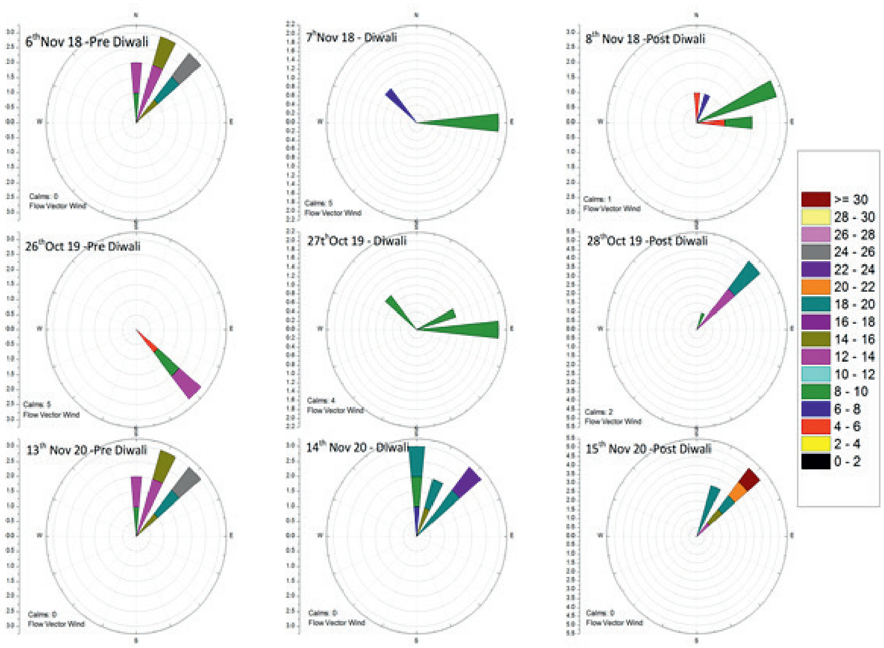

Figure 1: Wind roses during pre, Diwali and post Diwali days over Visakhapatnam in 2018, 2019 and 2020.

punctuated by northerlies and easterlies. Hence, traces of remaining pollutants tend to move south-westward and southward of the city region. The conspicuous post Diwali north-easterly winds in 2019 (with a peak wind speed of 18 to 20 kmph) and 2020 (with a maximum wind speed of ≥ 30 kmph) keep forcing the remaining pollutants further south-westwards. Thus in 2020 shorter duration of the Diwali celebrations caused only a little quantum/concentration of pollutants which are further diluted, dispersed and hence loaded smaller amounts of the pollutants into the atmosphere essentially because of the stronger wind speed.

Particulate matter of small diameter (2.5 μm) is the most harmful as it can easily reach the lungs through the respiratory tract. The short-term effects include irritation of the nose, eyes and lungs and breathing discomfort. As Diwali falls in the winter season, the low winds and humidity are the reasons for high concentrations of $PM_{2.5}$ in the air. The fireworks start around 18:00 hrs on Diwali night. The pollution levels start rising and reach the maximum value when firework activity peaks. The 24-hour average concentrations of $PM_{2.5}$ are shown in Figure 2. After two hours of firework activity, $PM_{2.5}$ started increasing and peaked at 500 μg/m^3 in 2018 and 2019 and at 419 μg/m^3 in 2020. The peak values lasted for 10 hrs in 2018, 2-3 hrs in 2019 and only for about an hour in 2020. On Diwali day during the years 2018, 2019 and 2020 the average concentrations of $PM_{2.5}$ at night were found to be 408.33 μg/m^3, 242.91 μg/m^3, 174.08 μg/m^3, respectively, which are 5.8, 5.23, and 3.63 times higher than their respective day time levels.

The particulate matter of diameter 10 μm remains hovered/settled longer in stable atmosphere. It causes respiratory problems as it carries a mixture of toxic pollutants due to fireworks. On Diwali night during the study period, the average concentrations were 347.83 μg/m^3, 164.91 μg/m^3, and 136 μg/m^3, respectively, for 2018, 2019 and 2020. The night concentrations increased significantly by 3.54, 1.68 and 1.55 times than their day-time levels in the consecutive years respectively. After two hours of firework activity, PM_{10} elevated to 451 μg/m^3, 500 μg/m^3 and 321 μg/m^3, for the three consecutive years (Figure 3). In 2020, the elevation lasted only for an hour while it lasted for two hours in 2019 and it remained elevated till the next day 5:00 a.m. in 2018.

The continuous cracking of fireworks releases toxic gases like SO_2, NO_2 and CO over a period of time. NO_2 can exacerbate chronic bronchitis and is a deep lung irritant too. Fireworks contain 75 % of potassium nitrate which when burnt with carbon and sulphur produce SO_2. SO_2 can adsorb fine particles in the presence of particulate matter and is particularly most dangerous because it carries the particles deep into the lungs and it can aggravate chronic bronchitis.

The diurnal patterns of various pollutants during the festive period for the three consecutive years are shown in Table 2.

In 2018, during Diwali night the maximum values of NO_2, SO_2 and CO recorded are 121 μg/m^3, 104 μg/m^3 and 77 μg/m^3, respectively, as shown in Figures 4-6. The average concentrations of NO_2, SO_2 and CO during Diwali night for the same year are 82.75 μg/m^3, 65.33 μg/m^3 and 44.75 μg/m^{3}which are 2.25, 8.6 and 1.40 times higher than their respective day time levels. Between 19:00 and 3:00 hrs the next day, SO_2 exhibited an increasing trend in night time concentrations compared to day time values. In the

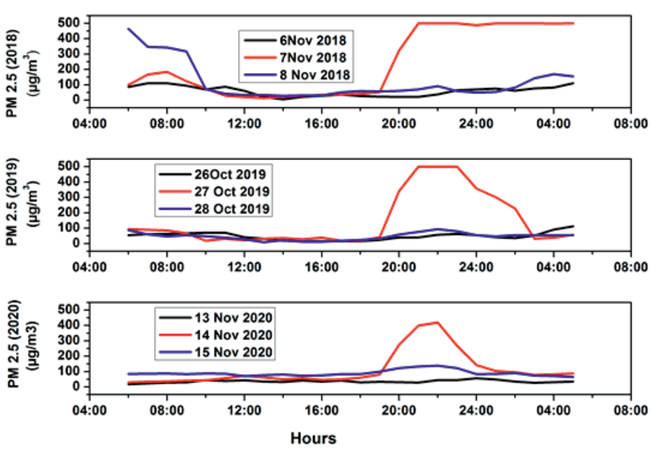

Figure 2: Diurnal variations of $PM_{2.5}$ concentrations for pre-Diwali, Diwali and post Diwali days for the years 2018, 2019 and 2020.

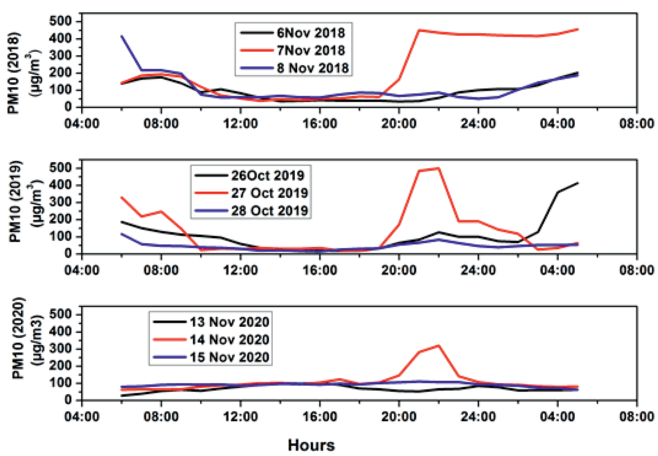

Figure 3: Diurnal variations of PM_{10} concentrations for pre-Diwali, Diwali and post Diwali days for the years 2018, 2019 and 2020.

Table 2: Diurnal patterns of various pollutants during the festival

Pollutant concentration in ambient air (µg/m³)	*Day*	*2018*			*2019*			*2020*		
		Day	*Night*	*24 hrs*	*Day*	*Night*	*24 hrs*	*Day*	*Night*	*24 hrs*
$PM_{2.5}$	Pre Diwali	60.83	55.91	58.37 ±32.81	43.58	52	47.79 ±25.18	34.25	36.91	35.58 ±8.87
	Diwali	69.58	408.33	238.95 ±215.86	46.41	242.91	144.66 ±171.71	47.91	174.08	111 ±111.39
	Post Diwali	149.41	87.33	118.37 ±122.43	36.25	56.91	46.58 ±23.70	81	97.25	89.12 ±19.98
PM_{10}	Pre Diwali	93.08	92.91	93 ±52.67	79.75	131.41	105.58 ±98.76	73.66	65.58	69.62 ±18.84
	Diwali	98.16	347.83	223 ±171.57	98.16	164.91	131.54 ±141.55	87.33	136	111.66 ±62.58
	Post Diwali	130	97.5	113.75 ±84.42	39.41	52	45.70 ±27.87	91.83	92.5	92.16 ±11.63
NO_2	Pre Diwali	46.08	69.41	57.75 ±34	28.25	85.33	56.79 ±33.02	26.16	29.16	27.66 ±9.13
	Diwali	36.75	82.75	59.75 ±43.94	37.83	42.41	40.12 ±24.43	20.75	18.91	19.83 ±5.27
	Post Diwali	35.66	48.91	42.29 ±38.49	24.33	23.5	23.91 ±11.27	17	16.91	16.95 ±2.56
SO_2	Pre Diwali	7.5	10.58	9.04 ±8.22	19.33	48.33	33.83 ±18.73	12.58	10.5	11.54 ±8.13
	Diwali	7.58	65.33	36.45 ±41.71	18.75	32.16	25.45 ±13.31	5.16	6.33	5.75 ±3.30
	Post Diwali	8.75	7.58	8.16 ±8.46	25.5	27.16	26.33 ±3.17	11.66	8.91	10.29 ±5.23
CO	Pre Diwali	29.91	46.83	38.37 ±16.80	24.91	82.25	53.58 ±35.13	28.66	34.83	31.75 ±7.89
	Diwali	31.91	44.75	38.33 ±19.04	46.5	28.5	37.5 ±29.89	28.16	28.33	28.25 ±2.78
	Post Diwali	30.16	38.25	34.20 ±13.52	28.08	27.91	28 ±6.14	28.33	29.58	28.95 ±4.09
Ozone	Pre Diwali	37.75	15.75	26.75 ±20.80	50	14	32 ±24.73	49.25	51.33	50.29 ±9.37
	Diwali	47.75	49.75	48.75 ±22.38	30.75	16.41	23.58 ±14.13	58.75	73.08	65.91 ±12.03
	Post Diwali	42.08	31.41	36.75 ±17.58	28.33	39.83	34.08 ±9.09	68.41	74.83	71.62 ±8.06

Day: 6 a.m. to 6 p.m. Night: 6 p.m. to 6 a.m. 24 hrs average with standard deviation
Source: Central Pollution Control Board.

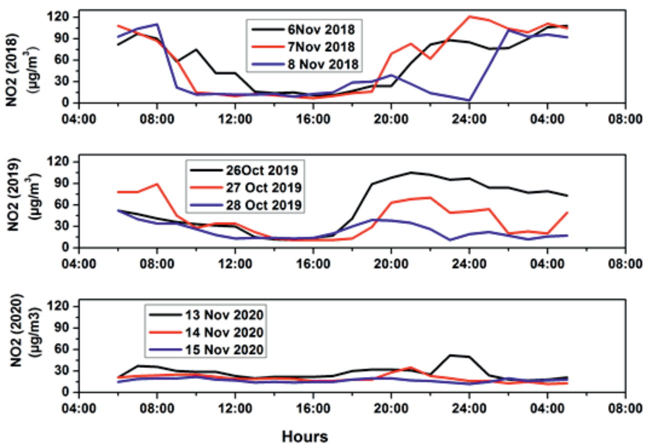

Figure 4: Diurnal variations of NO_2 concentration for pre-Diwali, Diwali and post Diwali days for the years 2018, 2019 and 2020.

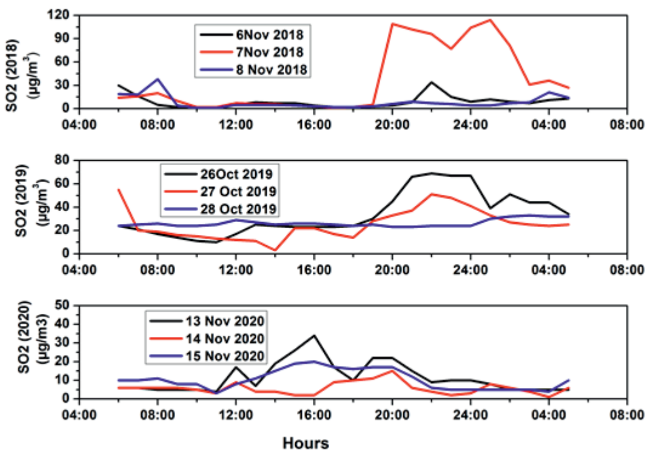

Figure 5: Diurnal variations of SO_2 concentration for pre-Diwali, Diwali and post Diwali days for the years 2018, 2019 and 2020.

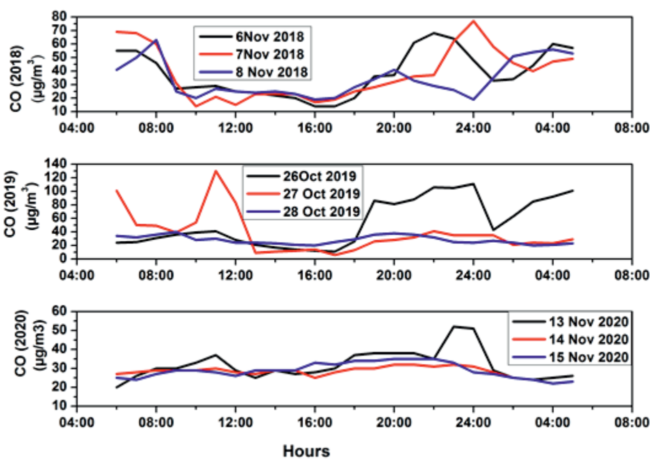

Figure 6: Diurnal variations of CO concentration for pre-Diwali, Diwali and post Diwali days for the years 2018, 2019 and 2020.

case of NO_2, the first peak was observed at 21:00 hrs and exhibited a little depression before peaking again at 00:00 hr. CO started increasing sharply when the burning of fireworks started at 18:00 hrs and reached a maximum at 00:00 hrs.

However, in 2019, the maximum values of NO_2, SO_2 and CO recorded are 70 μg/m^3, 51 μg/m^3 and 41 μg/m^3, respectively. The average night concentrations of NO_2 and SO_2 were found to be 42.41 μg/m^{3}and 32.16 μg/m^3, respectively which are 1.12 and 1.71 times higher than their respective day time values. Interestingly, CO did not exceed day time value. In 2020, the trend is quite different. The average night concentration of NO_2 did not exceed day time value, CO remained the same during day and night times and a small raise in SO_2 by 1.22 times higher than the average day time value is observed.

Photolysis of NO_2 in the presence of sunlight forms ozone during day time. Ozone formation at night is not possible due to the absence of sunlight. However, the radiative energy produced due to colour fireworks helps in the formation of ozone during Diwali nights. The energy radiated enables the reaction $O_2 + O \rightarrow O_3$. When ozone mixes with air pollutants it creates a condition called smog (a portmanteau word for smoke+fog). Smog condition reduces visibility and causes irritation and inflames eye tissues. On Diwali night in 2018 at 00:00 hrs, the concentration of ozone increased to a maximum value of 76 μg/m^3 and in 2020 it reached a maximum of 80 μg/m^3 (Figure 7). In 2019, the increase in the ozone layer was seen post Diwali day. The average night-time concentration in O_3 is higher than compared to day-time levels in the years 2018 and 2020 which can be attributed to the burning of coloured fireworks.

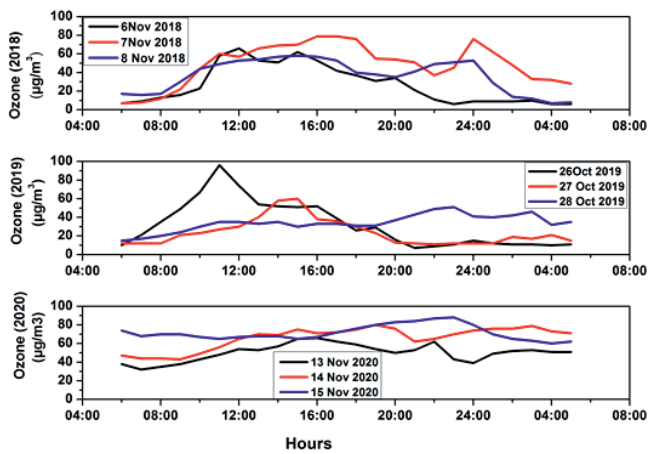

Figure 7: Diurnal variations of ozone concentration for pre-Diwali, Diwali and post Diwali days for the years 2018, 2019 and 2020.

Table 3 depicts the ratio of $PM_{2.5}$ to PM_{10} for the study period during day and night time. This ratio helps identify the sources of $PM_{2.5}$ and PM_{10} and also the contribution of $PM_{2.5}$ directly and PM_{10} indirectly. During Diwali night and post-Diwali day, the ratios were very high indicating the higher concentrations of $PM_{2.5}$ during festive days. In 2018, during Diwali night and after Diwali day the ratios were 1.17 and 1.14 while in 2019 and 2020, they were 1.47 and 1.09, 1.28 and 1.05, respectively. When compared to 2018 and 2020, a high ratio value of 1.47 is recorded during Diwali night in 2019. The day and night time ratios were high during post-Diwali period (8th Nov 18, 28th Oct 19, 15th Nov 20) in all three years.

Correlation

The correlation of particulate matter with pollutants is shown in Table 4. $PM_{2.5}$ and PM_{10} show a strong correlation with NO_2 and CO and a strong negative correlation with O_3 in 2020 whereas, in the case of SO_2, the particulate matter is strongly correlated with SO_2 in 2018 and 2019 and is negatively correlated in 2020. This shows that the increasing trend in particulate matter is related to an increase in NO_2. SO_2 is formed when potassium nitrate is burnt with carbon and sulphur and fireworks contain 75% of potassium nitrate. In 2020, the negative correlation of particulate matter with SO_2 indicated that the burning rate of crackers is reduced due to restricted timings and also reduced preference for a particular type of crackers that emits SO_2. The high correlation coefficients during Diwali night show that the burning of fireworks is a strong source of air pollution.

Conclusions

COVID–19 with imposed restrictions provided an opportunity to study the impact of firework activity on air quality. The significant finding is that the average concentrations of PM $_{2.5}$, PM_{10} and O_3 during Diwali night are more than their respective day time values in 2020 but these values are far lower and their environmental residence and suspension time in air are quite less in comparison to the two previous years of Diwali. There is no significant variation in NO_2, SO_2 and CO for the same year. In 2020, $PM_{2.5}$ and PM_{10} exhibited a strong positive correlation with NO_2 and CO, and a low negative correlation with SO_2 but a high correlation with O_3. Enhanced levels of

Table 3: Ratios of $PM_{2.5}$ to PM_{10} during day and night time

	$PM_{2.5}$		*PM_{10}*		*$PM_{2.5}/PM_{10}$*	
	Day	*Night*	*Day*	*Night*	*Day*	*Night*
6th Nov 18	60.83	55.91	93.08	92.91	0.65	0.60
7th Nov 18	69.58	408.33	98.16	347.83	0.70	1.17
8th Nov 18	149.41	87.33	130	97.5	1.14	0.89
26th Oct 19	43.58	52	79.75	131.41	0.54	0.39
27th Oct 19	46.41	242.91	98.16	164.91	0.47	1.47
28th Oct 19	36.25	56.91	39.41	52	0.91	1.09
13th Nov 20	34.25	36.91	73.66	65.58	0.46	0.56
14th Nov 20	47.91	174.08	87.33	136	0.54	1.28
15th Nov 20	81	97.25	91.83	92.5	0.88	1.05

Table 4: Correlation between particulate matter and gaseous pollutants during Diwali night

	2018					*2019*					*2020*				
	PM_{10}	*NO_2*	*SO_2*	*CO*	*Ozone*	*PM_{10}*	*NO_2*	*SO_2*	*CO*	*Ozone*	*PM_{10}*	*NO_2*	*SO_2*	*CO*	*Ozone*
$PM_{2.5}$	0.97	0.89	0.58	0.62	-0.49	0.85	0.81	0.89	0.76	-0.77	0.94	0.82	-0.04	0.64	-0.80
	$PM_{2.5}$	*NO_2*	*SO_2*	*CO*	*Ozone*	*$PM_{2.5}$*	*NO_2*	*SO_2*	*CO*	*Ozone*	*$PM_{2.5}$*	*NO_2*	*SO_2*	*CO*	*Ozone*
PM_{10}	0.97	0.86	0.46	0.64	-0.48	0.85	0.79	0.75	0.69	-0.64	0.94	0.77	-0.06	0.57	-0.81

particulate matter and gaseous pollutants were observed during firework activity in 2018 and 2019. In 2019, the low pollution levels and wash out of pollutants as compared to 2018 could be due to the unseasonal rainfall soon after the festival. From these observations, we conclude that with unfavourable or nonconducive meteorological conditions in 2019 and restrictions on firework activity in 2020, only a limited time raise in pollutants due to firework activity during Diwali night is observed. Compared to 2018 and 2019, improvement in air quality is observed in Visakhapatnam during the festival period of 2020. Notwithstanding the pandemic fears and its potential negative impact on the lives of people, the positive inference from the above study is that administrative or legislative restrictions on the use of certain prohibited chemicals can bring about a qualitative sea change in the control and dispersal of pollutants in the ambient air. Thus, in 2020, shorter durations of the Diwali celebrations caused a low concentration of pollutants which are further diluted, dispersed and hence loaded smaller amounts of the pollutants into the atmosphere essentially because of the stronger wind speed.

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Conflicts of Interest

The authors proclaim that there is no conflict of interest and also disclaim that they have no motive in writing this paper**.**

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