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COVID-19 Implicated ban on Diwali fireworks: a case study on the air quality of Rajasthan, India

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Abstract
Diwali is a five-day festival celebrated every year with lamp illumination and bursting of firecrackers in India. Considering the present situation of the COVID-19 pandemic, the Rajasthan government imposed a ban on firecrackers during the five-day festivities in the year 2020 to tackle air pollution caused by the emission of harmful pollutant gases from their burning. This paper has assessed the concentration of PM10, PM2.5, CO and SO2 pollutants, which are released from fireworks in large amounts in the environment during the Diwali festival. Seven air quality monitoring stations viz. Ajmer, Alwar, Jaipur, Jodhpur, Kota, Pali and Udaipur in Rajasthan state were selected to examine the effect of a ban on the use of firecrackers during the Diwali festival. The analysis was done by comparing the mean concentrations of baseline data and Diwali day data of 2019 and 2020. The results depict that the firecracker ban helped in declining the concentrations of all the air pollutants (PM2.5, PM10, CO and SO2) taken into consideration, which significantly improved the ambient air quality of Rajasthan during the Diwali festival, and it is suggested that such regulations should be implemented from time to time to improve the quality of air and human health effectively.

Keywords
Diwali festival, fireworks, air quality, pollutants, COVID-19, Rajasthan

Introduction

India is a country of festivals. Festivals are a way of showing traditions, customs, cultures, rituals, history, beliefs, and glory to pay homage to deities by folks. Diwali or Deepawali is the biggest and much-awaited festival in India. It is a festival of lights celebrated every year in October or November and lasts for five days. It involves the illumination of lamps or diyas and burning of firecrackers, which has become a tradition to express joy, cheer, and festivity since time immemorial in India. During the Diwali festival, the firecracker bursting at a massive level by the entire country for a short duration incorporates a huge amount of smoke and other hazardous

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chemicals into the ambient environment, which substantially aggravates the levels of air pollution, leading to severe health hazards. Firecrackers release aerosols, especially particulate matter and toxic gases in the environment, which cause air pollution, and eventually leads to acute and chronic health effects in humans. The burning of firecrackers leads to the addition of heavy metals like aluminium, manganese, and cadmium etc., in the ambient air environment during the period of the Diwali festival in India, as these heavy metals are associated with rigorous health hazards (Ambade, 2018; Burkart et al., 2013; Roberts, 2013; Sarkar et al., 2010; Tao et al., 2014). Fireworks are also a source of trace organic pollutants (Fleischer et al., 1999). The authors observed a fourfold increment in concentration of dioxin and furan during the festival on Bonfire night in Oxford (England). Barman et al. (2008) reported an augmentation in the concentration of PM_{10}, SO_2, and NO_x by 2.49, 1.95, and 1.79 folds on the Diwali compared to the Pre-Diwali period and by 5.67, 6.59, and 2.69 times on the Diwali compared to normal days in Lucknow, India. Joly et al. (2010) reported an increment of 1000 folds in $PM_{2.5}$ concentration against background level due to firecrackers. Tian et al. (2014) evaluated in his study that fireworks increased $PM_{2.5}$ concentration up to 29.66% and PM_{10} concentrations up to 23.40% during heavy-firework period in comparison to $PM_{2.5}$ concentration up to 7.18% and PM_{10} concentrations up to 4.28% during light-firework period Tsai et al. (2012) found out ten times more concentration of K, Mg, Pb and Sr in $PM_{2.5}$ along with increment in organic/ elemental carbon (OC/ EC) ratio by 2.8 during Taiwan's Lantern festival. Fireworks lead to the formation of spew clouds of polluted contaminants in ambient air, which downturns the air quality and curtail visibility (Vecchi et al., 2008), and also poses life-threatening health crisis to humans (Ravindra et al., 2003; Wang et al., 2007). The abrupt outbreak of higher concentration of air pollutants because of massive fireworks enhanced the possibility of heart, lung, and nervous system damage by causing asthma, bronchitis, emphysema, etc. (Mishra et al., 2016). Gasping of smoke during fireworks settings causes fever and cough in humans (Hirai et al., 2000). Long-term exposure to $PM_{2.5}$, NO_2, and SO_2 reduces lung capacity and causes respiratory distress.

Degraded air quality is a major attribute to acute and chronic respiratory illness. Humans with respiratory and cardiovascular distress are vulnerable to COVID-19 as it can be fatal; hence, air pollution is a major contributing health burden in this COVID pandemic (WHO, 2020). Firecrackers burning during Diwali festivity can introduce large concentrations of pre-existing PM_{10}, $PM_{2.5}$, NO_2 and SO_2 in the air, which might enhance the COVID-19 infection occurrence in humans.

The health implications of COVID-19 due to poor air quality led to pressure on the governing bodies to respond to this crisis by implementing a strict ban on fireworks during Diwali 2020. In this wake, the Government of Rajasthan, India, imposed stringent guidelines to restrict the sale and use of firecrackers during the Diwali festival 2020 to curb the air pollution levels in Rajasthan to safeguard the environment and public health. Rajasthan is the largest state of India by area and the seventh-largest state by population. It has diverse geographical conditions like mountains, plains, and deserts, which attribute a key role in air quality status by dispersion of air pollutants.

Therefore, the objective of this study is to assess the air quality outcomes of the enforced ban on celebratory use and selling of firecrackers in Rajasthan by considering seven cities, namely, Ajmer, Alwar, Kota, Jaipur, Jodhpur, Pali, and Udaipur during Diwali festival 2020. The data of major air pollutants $PM_{2.5}$, PM_{10}, CO, and SO_2, were collected from the official website of the Central Pollution Control Board (CPCB), India, during the Diwali fiesta of 2019 and 2020. To investigate the profound impact of the ban on the flaring of firecrackers on the air quality, the data of Diwali festival 2020 was compared with the data of Diwali festival 2019 among the selected cities of

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Rajasthan.

Materials and Methods

A total of seven cities of Rajasthan, India, namely, Ajmer, Alwar, Kota, Jaipur, Jodhpur, Pali, and Udaipur, were selected to evaluate the effect of a ban on fireworks on air quality during the Diwali festival 2020. The location of cities is shown in Table 1 and Figure 1. Total four air pollutants were studied: PM_{10}, $PM_{2.5}$, CO (carbon monoxide), and SO_2 (sulfur dioxide). The data regarding the concentration of PM_{10}, $PM_{2.5}$, CO, and SO_2 were obtained from the online portal of CPCB, India (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing).

The concentration of PM_{10}, $PM_{2.5}$, and SO_2 was taken at intervals of 24 hours, while the concentration of CO was taken at 8-hour intervals. To explore the profound impact of the ban on fireworks on air quality, a comparative study was done between the concentration of PM_{10}, $PM_{2.5}$, CO, and SO_2 of Diwali festival 2020 and Diwali festival 2019. The data of the aforementioned air pollutants were taken for Diwali festival 2020 and Diwali festival 2019 in two phases.

Table 1. *Details of selected cities of Rajasthan, India*

City Name	Coordinates	No. of Air Quality Monitoring (AQM) Stations
Ajmer	26° 26’ 59.6256’’ N, 74° 38’ 23.6940’’ E	01
Alwar	27° 33’ 39.3552’’ N, 76° 37’ 30.0540’’ E	01
Jaipur	26° 55’ 19.4520’’ N, 75° 46’ 43.9860’’ E	03
Jodhpur	26° 14’ 20.2100” N, 73° 01’ 27.5100” E	01
Kota	25° 09’ 46.7928’’ N, 75° 50’ 43.1592’’ E	01
Pali	25° 46’ 16.7340’’ N, 73° 19’ 25.2660’’ E	01
Udaipur	23° 32’ 09.6800” N, 91° 29’ 13.1500” E	01

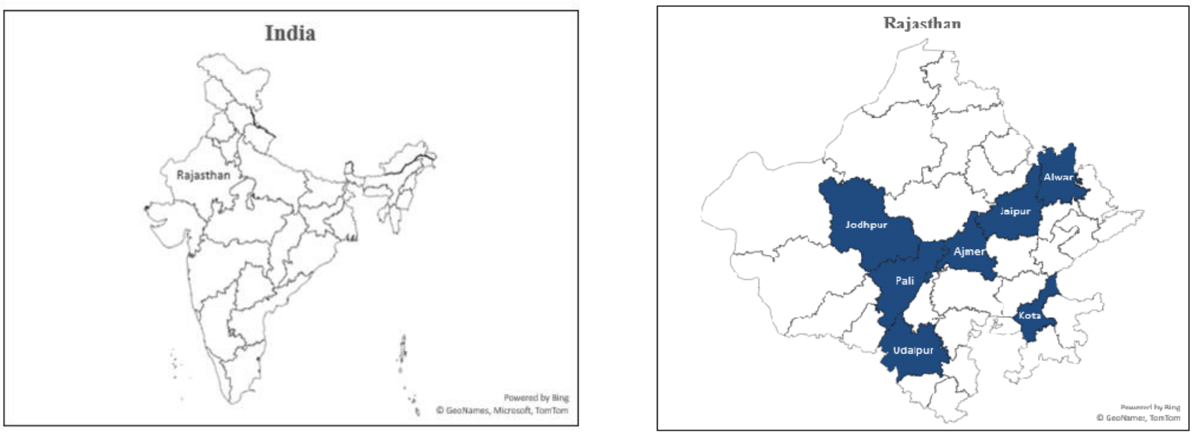

Figure 1. *Location map of seven cities of Rajasthan.*

In the first phase, baseline data (BD) were generated by averaging the data of 15 days before Diwali, and in the second phase, data were taken on Diwali Day (DD) for 24 hours from 06.00 PM to the next day 06.00 PM. Diwali was celebrated on 27th October in 2019 and 14th November in 2020.

Results and discussion

The concentrations of the air pollutants ($PM_{2.5}$, PM_{10}, CO, and SO_2) taken into account for the seven cities of Rajasthan (India) are mentioned in Table 2.

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The mean concentrations of $PM_{2.5}$ pollutant in baseline data 2019 (BD-2019) were maximum for Jodhpur (96.88 μg/m^3) and minimum for Alwar (37.52 μg/m^3), while on Day of Diwali 2019 (DD-2019), it was reported highest and lowest in Jaipur (221.23μg/m^3) and Alwar (88.22 μg/m^3), respectively. The attributed $PM_{2.5}$ concentrations for baseline data 2020 (BD-2020) were ranged from highest 124.05 μg/m^3 (Jodhpur) to the lowest 62.51 μg/m^3 (Udaipur), and on Day of Diwali 2020 (DD-2020), it was maximum of 172.67 μg/m^3 at Jodhpur and minimum of 64.03 μg/m^3 at Udaipur, sequentially.

The percentage variations in concentrations of $PM_{2.5}$ during Diwali 2019 for selected cities were: Ajmer (+182%), Alwar (+135%), Jaipur (+260%), Jodhpur (+31%), Kota (+99%), Pali (+161%) and Udaipur (+175%) as compared to Diwali 2020 i.e., Ajmer (+24%), Alwar (+24%), Jaipur (-21%), Jodhpur (+39%), Kota (+93%), Pali (+12%) and Udaipur (+2%), respectively (Table 2 and Figure 2).

A receding trend in the percentage variation of $PM_{2.5}$ concentrations was observed in all the cities except Jodhpur on Diwali in the year 2020 as compared to Diwali 2019. In the case of Jodhpur, its topographical features, Thar desert, arid and semi-arid climatic zones, and thermal inversion during winter contributes to dust particles in the atmosphere (CPCB, 2021), which may be a possible reason for the slight increase in $PM_{2.5}$ concentration on Diwali in the year 2020. The concentration of PM_{10} and $PM_{2.5}$ was reported by Thakur et al. (2010), more than 6 times and 4 times respectively on Deepawali compared to its baseline levels at Howrah, India.The concentration of PM_{10} ranged between 202.92 μg/m^3 (Jodhpur) to 84.76 μg/m^3 (Alwar) in BD-2019, while on DD-2019, it was observed to be maximum in Jaipur (322.69 μg/m^3) and minimum in Alwar (122.86 μg/m^3). In BD-2020, the concentration of PM_{10} was observed highest at Jodhpur (253.56 μg/m^3) and lowest at Alwar (117.66 μg/m^3), while on DD-2020, it was maximum at Jodhpur (314.20 μg/m^3) and minimum at Udaipur (135.98 μg/m^3).

The reported concentration of CO in BD-2019 fell in the range of 1.14 mg/m^3 to 0.66 mg/m^3 for Jodhpur and Kota, respectively, whilst DD-2019 maximum and minimum concentrations were 2.09 mg/m^3 and 0.74 mg/m^3 for Jodhpur and Kota, respectively. The outlined highest and lowest concentrations for BD-2020 were 1.71 mg/m^3 and 0.75 mg/m^3 for Jodhpur and Pali, though DD-2020 were attributed as 2.29 mg/m^3 and 0.83 mg/m^3 for Jodhpur and Pali, respectively.

The diminution in percentage variation in the average concentration of CO pollutant was observed on comparison of Diwali 2019 and 2020 data. Diwali 2019 percentage variations were in the following order: Ajmer (+58%), Alwar (+41%), Jaipur (+34%), Jodhpur (+84%), Kota (+12%), Pali (+76%) and Udaipur (+31%). However, Diwali 2020 percentage variations in the average concentration of CO pollutant were reported as: Ajmer (-32%), Alwar (+21%), Jaipur (-28%), Jodhpur (+34%), Kota (+19%), Pali (+10%) and Udaipur (-25%) (Table 2 and Figure 4).

A downtrend variation in CO concentration was recorded at Ajmer, Alwar, Jaipur, Jodhpur, Pali and Udaipur except for Kota. This decline in CO concentration showed the effectiveness of the implicated ban. In Kota, a little inclination in the percentage variation of CO was observed because of the operation of coal/gas-based thermal power plants, which is a major source of CO, as the burning of fossil fuel releases CO in the atmosphere.

The observed concentration of SO_2 in BD-2019 ranged from 14.09 μg/m^3 at Alwar and 5.80 μg/m^3 at Ajmer, while DD-2019, it was reported maximum of 24.08 μg/m^3 at Jaipur and minimum of 7.93 μg/m^3 at Ajmer. The SO_2 concentration for BD-2020 was highest and lowest with 13.84 μg/m^3 at Udaipur and 9.33 μg/m^3 at Pali, respectively as compared to DD-2020 ranged from 15.10 μg/m^3 at Udaipur to 5.84 μg/m^3 at Ajmer, correspondingly. Diwali 2019 percentage variations in SO_2 were found as follows: Ajmer (+37%), Alwar (+24%), Jaipur (+81%), Jodhpur (+24%), Kota (+14%), Pali (+80%), and Udaipur (+12%), whereas downswing percentage variations in SO_2 was noticeable in

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Parameters	Year	City names	Ajmer	Alwar	Jaipur	Jodhpur	Kota	Pali	Udaipur
$PM_{2.5}$ (µg/m³)	2019	Baseline Data (BD-2019)	61.54	37.52	61.51	96.88	65.21	49.95	56.73
		Day of Diwali (DD-2019)	173.51	88.22	221.23	126.69	129.69	130.40	155.85
		% Variations	+182%	+135%	+260%	+31%	+99%	+161%	+175%
	2020	Baseline Data (BD-2020)	72.23	66.50	108.83	124.05	88.73	67.99	62.51
		Day of Diwali (DD-2020)	89.59	82.51	86.11	172.67	171.16	76.29	64.03
		% Variations	+24%	+24%	-21%	+39%	+93%	+12%	+2%
PM_{10} (µg/m³)	2019	Baseline Data (BD-2019)	111.30	84.76	136.07	202.92	114.30	108.32	136.56
		Day of Diwali (DD-2019)	238.30	122.86	322.69	281.49	232.70	229.30	230.20
		% Variations	+114%	+45%	+137%	+39%	+104%	+112%	+69%
	2020	Baseline Data (BD-2020)	137.46	117.66	202.14	253.56	148.62	132.87	143.25
		Day of Diwali (DD-2020)	143.22	152.30	182.05	314.20	229.51	147.71	135.98
		% Variations	+4%	+29%	-10%	+24%	+54%	+11%	-5%
CO (mg/m³)	2019	Baseline Data (BD-2019)	0.85	0.85	1.02	1.14	0.66	0.72	1.11
		Day of Diwali (DD-2019)	1.34	1.20	1.37	2.09	0.74	1.26	1.45
		% Variations	+58%	+41%	+34%	+84%	+12%	+76%	+31%
	2020	Baseline Data (BD-2020)	1.23	1.16	1.68	1.71	1.01	0.75	1.40
		Day of Diwali (DD-2020)	0.84	1.41	1.21	2.29	1.20	0.83	1.05
		% Variations	-32%	+21%	-28%	+34%	+19%	+10%	-25%
SO_2 (µg/m³)	2019	Baseline Data (BD-2019)	5.80	14.09	13.27	10.52	8.21	8.18	9.15
		Day of Diwali (DD-2019)	7.93	17.42	24.08	13.03	9.40	14.74	10.21
		% Variations	+37%	+24%	+81%	+24%	+14%	+80%	+12%
	2020	Baseline Data (BD-2020)	10.69	11.93	11.94	11.34	9.53	9.33	13.84
		Day of Diwali (DD-2020)	5.84	14.04	10.95	13.27	9.84	8.44	15.10
		% Variations	-45%	+18%	-8%	+17%	+3%	-9%	+9%

Table 2. *Concentrations of air pollutants (PM2.5, PM10, CO, and SO_2) of selected cities of Rajasthan, India during Diwali festival 2019 and Diwali festival 2020.*

Diwali 2020 as compared to 2019, which were in the following order such as Ajmer (-45%), Alwar (+18%), Jaipur (-8%), Jodhpur (+17%), Kota (+3%), Pali (-9%) and Udaipur (+9%) (Table 2 and Figure 5). The SO_2 percentage variation compared between Diwali 2019 and 2020 showed a significant reduction. However, this indicates the successful implication of a firework ban and night curfew governed by the state,which curbs vehicular pollution by restricting vehicular move- ments across the state. It is evident that firecrackers composed of potassium nitrate, sulfur, and carbon on burning emanate gases like SO_2 and CO_2 (Ambade,2018). Hence, the ban on crackers in Rajasthan was effective and successful. Barman et al. (2008) reported an average increase in SO_2, NO_X, PM_{10}

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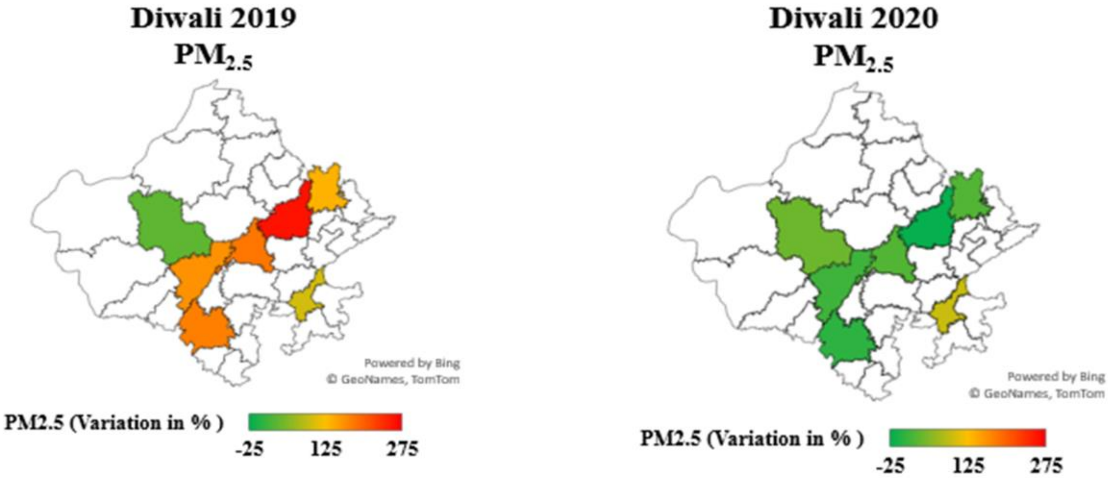

Figure 2. *Percentage variation in mean concentration of PM2.5 during Diwali 2019 and Diwali 2020.*

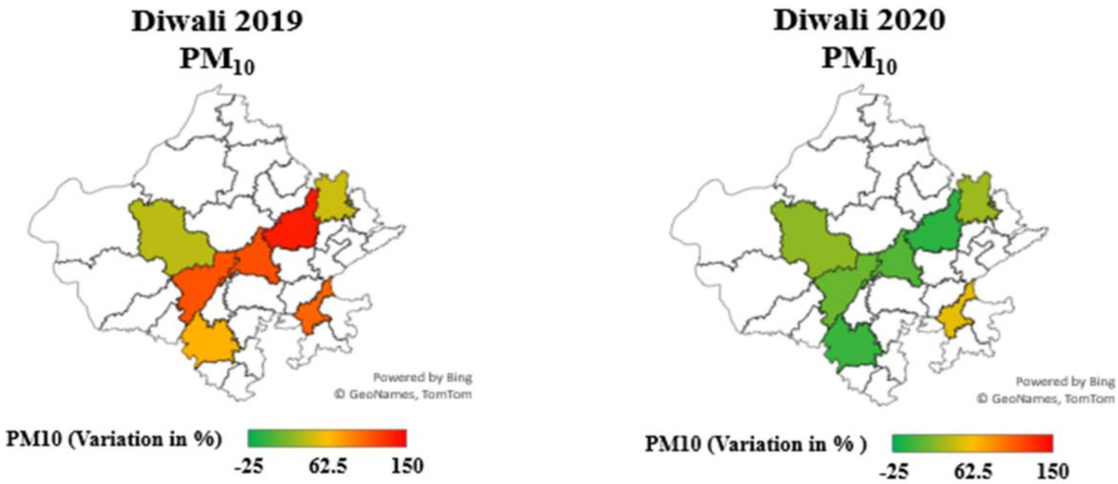

Figure 3. *Percentage variation in mean concentration of PM10 during Diwali 2019 and Diwali 2020.*

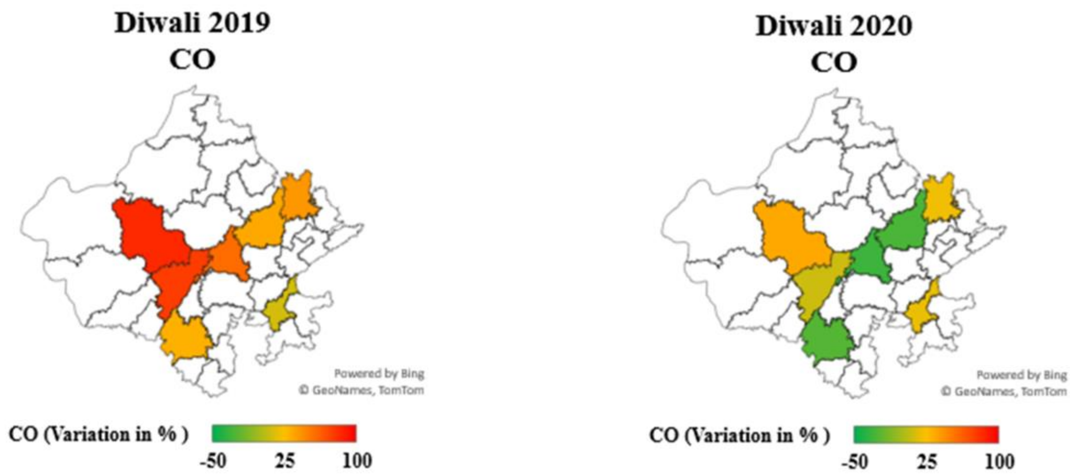

Figure 4. *Percentage variation in mean concentration of CO during Diwali 2019 and Diwali 2020*

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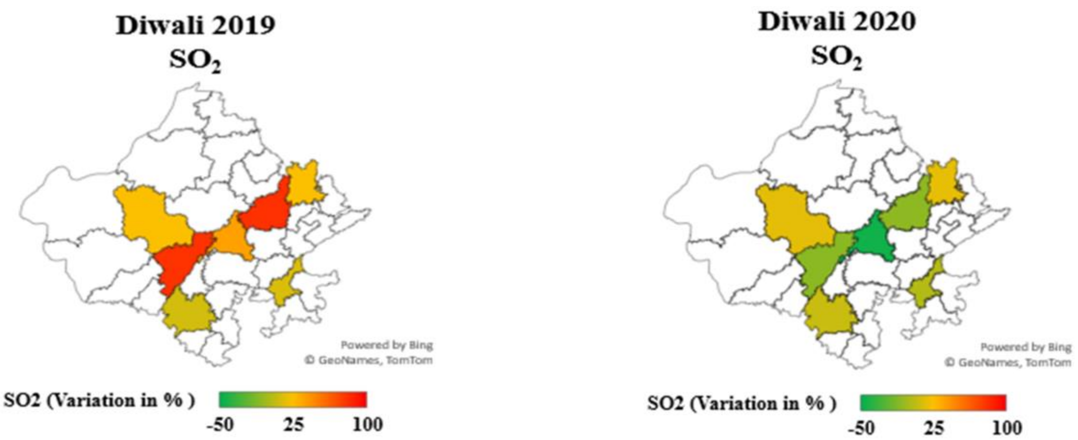

Figure 5. *Percentage variation in mean concentration of SO2 during Diwali 2019 and Diwali 2020.*

concentrations over the pre-Deepawali period and a normal day by 1.95 and 6.59 times, 1.79 and 2.69 times, and 2.49 and 5.67 times, respectively in Lucknow, India. According to a study conducted in Hisar, India, the short-term variation in air quality during Deepawali reported a 2–10 times increase in concentrations of total suspended particles (TSP), NO_2, SO_2, and PM_{10} over a typical winter day (Ravindra et al., 2003).

Conclusions

In 2020, the Rajasthan government imposed a banon firecrackers bursting during Diwali festival to curtail the release of air pollutants in the ambient environment to control the prevailing COVID-19 pandemic situation. The implementation of fireworks prohibition effectively improved the air quality and reduced the concentration of pollutants in the air across the state.

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Conflict of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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