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ORIGINAL PAPER

Air pollution in five Indian megacities during the Christmas and New Year celebration amidst COVID-19 pandemic

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Abstract

Urban air quality and COVID-19 have been considered significant issues worldwide in the last few years. The current study highlighted the variation in air pollutants (i.e., $PM_{2.5}$, PM_{10}, NO_2, and SO_2) profile between Christmas and new year celebrations in 2019, 2020, and 2021. It can be seen that the concentration of selected air pollutants shows a substantially higher concentration in celebration periods in all reported years. The results indicate that air pollutants values are always higher than permissible limits. This observation indicates that people gather and reunite during Christmas and new year celebrations than the preceding years (2020 and 2021) amidst the pandemic. In the pandemic year, a higher margin enhanced the transportation and firework-induced air pollutant load in urban city Jodhpur, Rajasthan. In all states, a significant tendency was observed to retain the concentration profile of air pollutants in baseline concentration for almost more than one week after the celebration. This study addresses the pandemic situation, but it also dealt with the air pollutant parameter that brings down the sustainable quality of the environment due to the high usage of private vehicles, and crackers. In addition, a study on COVID-19 (cases and death rate) indicates a clear picture of the increasing trend after the event in probably all states. Thus, this approach suggested that stringent law enforcement is needed to ameliorate gatherings/reunions and pollution levels due to such events.

Keywords COVID-19 · Air pollutants · Christmas · New year celebration · Transportation

Abbreviations

SO_2	Sulfur oxides
NO_2	Nitrogen oxides
CO	Carbon monoxide
CO_2	Carbon dioxide
NH_3	Ammonia
COVID-19	CoronaVirusDisease-2019
CPCB	Central pollution control board
PM	Particulate matter

1 Introduction

Christmas and new year celebrations are ubiquitous all over the world. It is a festival of joy and an occasion for a family reunion. It is celebrated in December every year globally. The celebration of Christmas or the birth anniversary of Jesus Christ is celebrated with great cheer and enthusiasm worldwide by Christians and other people. Exchange gifts, dancing, and burning firecrackers/sparklers are significant activities at night. People worldwide celebrate similar festivals like (Sky fest in Ireland, Diwali, lantern festival in china, etc.) with firecrackers. However, Christmas and New Year celebrations are coming with special attention, as billions of people worldwide celebrate them with burning firecrackers/sparklers. Several studies in different states/cities of the Indian region reported a higher concentration of air pollutants during festivals (Diwali, Christmas, New Year, etc.). This concentration is a combination of harmful metals (Rajendran et al. 2021), non-metals (Ambade et al. 2018), metalloids (Kulshrestha et al. 2004), and various chemical compounds (Gupta et al. 2020), and it is increased the concentration profile of air

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pollutants in the atmosphere. Recent studies (Klima et al. 2020; Liu et al. 2019; Camilleri and Vella 2010) highlighted particulate matter and toxic volatile organic compounds due to burning firecrackers and their residence time in the atmosphere through traveling long distances. A few research examples (Chhabra et al. 2020; Attri et al. 2001) on air pollution from burning firecrackers indicated a significant increment in the concentration of solid (aerosol, particles) and gaseous (Ozone, sulfur oxides (SO_2) and nitrogen oxides (NO_2), carbon monoxide (CO), carbon dioxide (CO_2), and ammonia (NH_3)) pollutants.

On the other side, several studies reported the impact of emission on human health during the celebration (Garaga and Kota 2020; Gowda et al. 2020; Garaga and Kota 2018). The total concentration of air pollutants in the ambient atmosphere due to the burning of firecrackers causes an array of respiratory diseases. Greenberg et al. (2017) observed the positive association of air pollutants (SO_2 and NO_2) with asthma and obstructive pulmonary diseases.

Last 2 years, the whole world is being threatened by the novel coronavirus (COVID-19) (Ranjbari et al. 2022; Ravina et al. 2021; Ranjbari et al. 2021; Rahimi and Abadi 2020). Wang et al. (2021) discussed the strong association between COVID-19 and health issues, with 3.5 million official casualties being reported and many remaining uncounted. Moreover, coronavirus strains have affected the normal situation (Gautam et al. 2022; Sarkar et al. 2021; Arora et al. 2021; Rajput et al. 2020; Humbal et al. 2019 and 2018). Varieties of fungal coinfections (i.e., yellow, black, and white) are the second partial concern during the pandemic (Sharma et al. 2022; Nori et al. 2021). Coccia (2021) highlighted the association between air pollution and COVID-19 infectivity. Recent studies (Chelani and Gautam 2021 and 2022; Travaglio et al. 2021; Ogen 2020; Zoran et al. 2020) show the connection of air pollutants ($PM_{2.5}$, O_3, NO_2) with coronavirus spread. According to available studies and research, It is clearly observed that the Indian region is the of the most affected area due to COVID-19 (Kumari et al. 2021). The government of India announced the lockdown on March 24, 2020, to break the chain of spreading virus infections. Moreover, it was updated according to various situations from 2020 to 2021 (Gangwar and Ray 2021; Soni 2021; Changotra et al. 2021). On the other side, positive points emerge from the environmental perspective as a significant air quality improvement, especially in all Indian megacities (Naqvi et al. 2021; Gautam 2020a and b; Sathe et al. 2021; Gautam and Brema 2020). Sudden fall in concentration profile of air pollutants reported due to complete stop of industrial activities and transportation which is very well known for air pollution sources (Bisht et al. 2022). Christmas and new year celebration in December 2020, Indian condition slowly, and everyday life came on track from the first wave of COVID-19. Despite the number of advertising and related information (COVID-19 lockdowns, curfew, limitation on transportation and use of firecrackers etc.) circulated by national and local government, we again received unpredicted second wave with significant cases like 0.4 million people per day (Mallapaty 2021).

As per detailed discussion, the present comparative air quality study in five states of India before (in the absence of COVID-19) and after Christmas and new year celebrations (in the presence of COVID-19). Selected states are highly populated and one of most affected due to COVID-19, with being populous states in India. Many studies included a few cities of selected states to show the significantly deteriorating air quality due to religious festivals and celebrations (Chattopadhyay and Shaw 2021; Anand et al. 2019; Chatterjee et al. 2013). During a pandemic, people did not celebrate the concerning factor with big numbers, which led to the lower total concentration of air pollutants than the previous year when there was no pandemic situation in India. Several studies have been reported on air quality and religious festival celebrations in India.

Moreover, the scientific community updated the improved status of air quality variation during a pandemic. However, literature could not be found to consider the effects of Christmas and new year celebrations amidst a pandemic. The current study adds first information about the degree of various air pollutants levels in five Indian states during the Christmas and new year celebrations amidst the COVID-19. The outcomes of the presented work provide a good platform for the policy managers, especially in the most populated and populous states, to create a sustainable urban atmospheric environment and look for similar avenues. The current study can be eye-openers for stakeholders and policymakers as air quality management in populated states or urban environments has become a challenge for present-day urban planners.

2 Material and methods

2.1 Study area

Andhra Pradesh, Maharashtra, Punjab, Madhya Pradesh, and Rajasthan are significant states of India (Fig. 1). The idea is to study the change in different human activities that becomes a source of air pollutant concentration in India. This comparative study included densely populated states to lower populated states.

Andhra Pradesh, located in south India along the coastal region, carries over 49,386,799 inhabitants. Maharashtra occupies the western and central peninsular region with the second most population in India. This business capital of India stimulates trade, varied culture, and tradition.

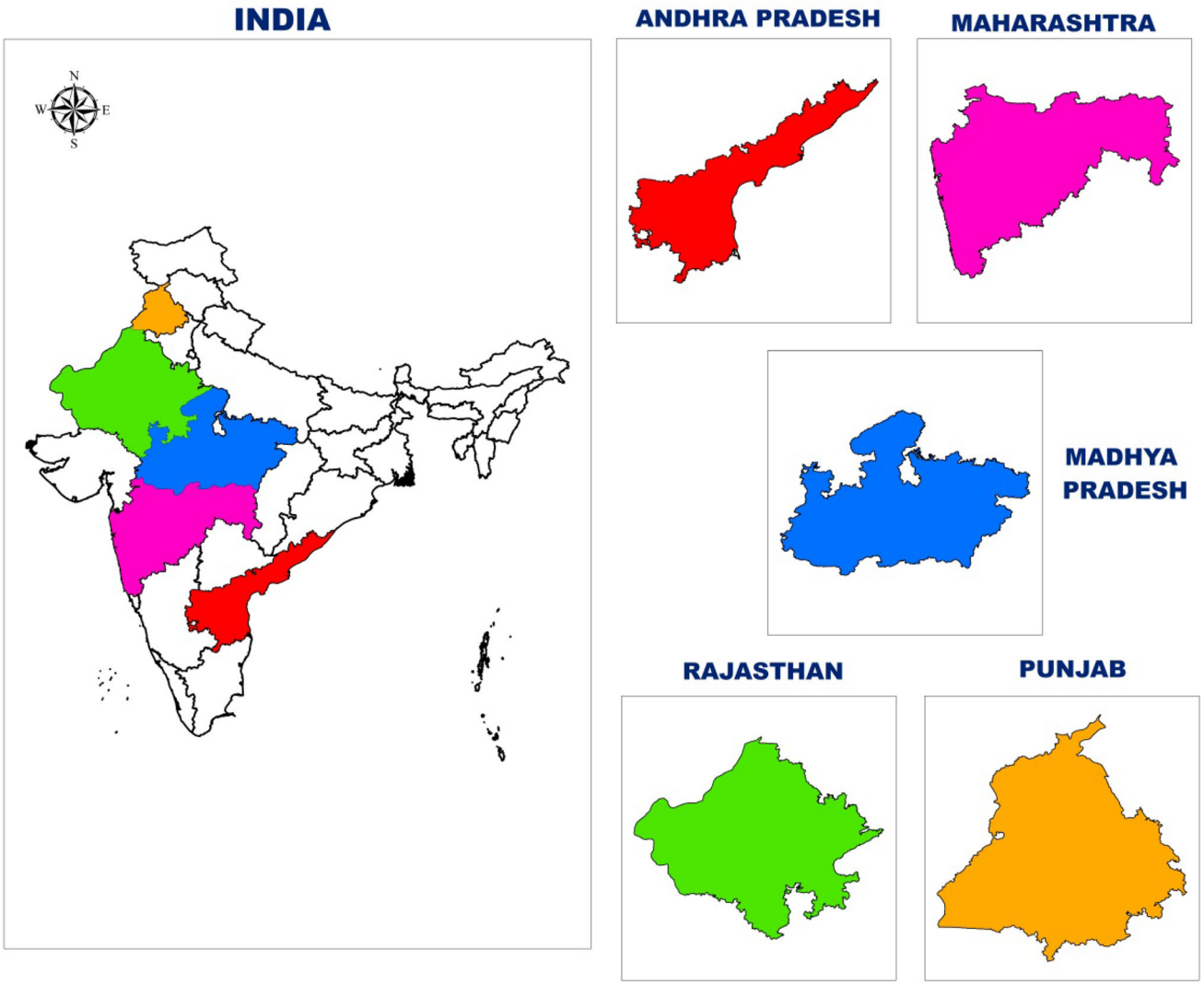

Fig. 1 Location map of the five states of India considered in this study

Madhya Pradesh, the central part of India's high population, spreads over 308,245 Km^2 holds more than 72 million. Punjab, the northern Indian state, lies on the border of India and Pakistan. This state has a different tradition and culture compared to other states that, in these festive days, the weather conditions were extreme. The largest Indian state, Rajasthan, with 342,239 sq Km, has 68,548,437 people.

The dry condition here was the significant inclusion of this state for this study. Major 4 to 6 cities from these selected states, and the pollutants levels and the change in meteorological parameters were analyzed for this study. The weather conditions will usually be deficient compared to other months in India. The temperature in Andhra Pradesh was mild compared to other states that experienced cold nights. The coastal winds along the coastal region of Maharashtra and Andhra Pradesh also had a significant role. The wind speed was low only in Punjab compared to other states that were more or less equal. Humidity was high in all states, excluding Punjab and Rajasthan. Punjab and Rajasthan, due to their high temperatures, have never seen a rise in humidity levels. This season changes in these areas with changes in human activities boosted and altered the pollutant levels.

2.2 Data used

Four air pollutants (i.e., $PM_{2.5}$, PM_{10}, NO_2, and SO_2) were monitored in this study. The data of these pollutants had been downloaded from CPCB (Central pollution control board) official website (https://app.cpcbccr.com/AQI_India/). Data were recorded in Automated Air monitoring stations which varied in numbers. Each monitoring station had different numbers of monitoring stations. The data

Table 1 The average concentration of the four pollutants presents in the air during the Christmas and New year of 2019, 2020 and 2021

Parameters (ug/m^3)	2019	2020	2021	Net variance	% of variance
Madhya Pradesh					
$PM_{2.5}$	105.6	78.82	68.69	− 115.8	− 24.39
PM_{10}	162.6	160.33	137.29	− 185.68	− 09.11
NO_2	41.21	49.62	52.91	− 37.92	11.59
SO_2	10.08	12.66	17.95	− 04.79	24.90
Rajasthan					
$PM_{2.5}$	78.76	96.76	97.04	− 78.48	09.44
PM_{10}	149.4	164.5	191.1	− 122.8	11.55
NO_2	23.50	41.34	39.98	− 24.9	19.87
SO_2	10.15	13.73	11.22	− 12.66	01.85
Andhra Pradesh					
$PM_{2.5}$	66.32	105.2	78.26	− 93.22	01.28
PM_{10}	78.51	174.9	122.5	− 130.9	06.17
NO_2	27.34	25.21	32.13	− 20.42	06.56
SO_2	10.56	14.84	09.87	− 15.52	− 10.72
Punjab					
$PM_{2.5}$	72.64	69.12	117.4	− 24.39	18.01
PM_{10}	118.9	25.85	230.9	86.15	− 135.5
NO_2	11.27	24.24	20.92	− 14.59	18.83
SO_2	10.81	07.67	11.77	− 06.72	− 03.03
Maharashtra					
$PM_{2.5}$	81.77	76.58	63.60	− 94.76	87.02
PM_{10}	127.3	174.9	126.5	− 175.6	113.4
NO_2	43.14	42.33	28.11	− 57.36	85.94
SO_2	27.85	11.63	24.07	− 15.41	18.01

were downloaded from this website for all the 26 cities of five states (Andhra Pradesh, Maharashtra, Punjab, Madhya Pradesh, and Rajasthan) from Dec 1 to Jan 4 of all 3 years (2019, 2020 and 2021). The reason for downloading data before and after Christmas new year days is to find the daily changes that had taken place in the concentration of pollutants, whereas different year data provided an idea about the changes during different years. CPCB had data available in different ways, including hourly data's, 8 h data set, and 24 h recorded data set. The 24 h recorded data set from 12 AM till the next day at 12 AM was used and considered the concentration level of that particular day. It was combined and used as pre-festive days (Dec 1–Dec 23) where human activities will be lower while compared to During festive days (Dec 24 to Jan 1), which will ultimately experience a rise in transportation movement, celebrations with firecrackers, and disposal of PM maters due to wind densely populated cities. Daily meteorological data was downloaded from NASA's official website POWER DATA ACCESS VIEWER, meteorological parameters temperature, wind speed, Relative humidity were downloaded for all the twenty-five cities and been used. This data will provide valuable information on how these parameters affect pollutants and how the rise in pollutants concentration level on post days will make even more impure for citizens.

2.3 Methodology

The pollutants are analyzed to understand the change in the concentrations for the year 2019–2022. The study is carried out for the three phases, i.e., pre-Christmas and new year, during the Christmas and new year, and post-Christmas and new year, where the net difference of the pollutants is calculated for the respective years. Box plots are prepared to observe the maximum, minimum, and median of the pollutants during the Christmas and new year; it also estimates the quartiles. A correlation between the entire pollutants is studied for each state. Later, understanding the metrological influence over the pollutants for the 3 years admits of COVID-19 is also calculated by the net variance and percentage obtained during the three phases taken in the study.

Table 2 Concentration profile (average) of selected air pollutants for consecutive years (2019,2020, and 2021) of various cities of five states in India during Christmas and new year celebration (i.e., Pre celebration (Dec 1–Dec 23), During celebratio1n (Dec 24–Jan 01), and Post celebration (Jan 01–Jan 04))

Pollutants	Cities	Dec 1–23	Dec 24–Jan 1	Jan 1–4	Pre-festival		Post-festival	
					Net variance	%	Net variance	%
2019								
Andhra Pradesh								
$PM_{2.5}$	Amaravati	60.00	61.25	34.64	01.25	02.03	− 26.61	− 76.81
	Tirupati	27.15	29.32	18.18	02.18	07.43	− 11.14	− 61.30
	Visakhapatnam	52.67	62.80	41.68	10.13	16.13	− 21.13	− 50.69
	Rajahmundry	53.24	57.21	33.68	03.97	06.95	− 23.53	− 69.87
PM_{10}	Amaravati	93.40	94.13	55.40	00.73	00.78	− 38.74	− 69.92
	Tirupati	52.01	50.07	23.05	− 01.94	− 03.87	− 27.02	− 117.2
	Visakhapatnam	92.28	22.45	77.22	− 69.83	− 311.1	54.77	70.93
	Rajahmundry	97.03	97.49	57.69	00.46	00.47	− 39.80	− 69.00
NO_2	Amaravati	17.77	14.01	14.99	− 03.76	− 26.81	00.98	06.52
	Tirupati	17.30	26.52	18.54	09.22	34.78	− 07.98	− 43.06
	Visakhapatnam	31.66	37.14	25.04	05.47	14.74	− 12.09	− 48.29
	Rajahmundry	19.58	21.32	17.70	01.74	08.16	− 03.62	− 20.44
SO_2	Amaravati	15.39	16.06	20.49	00.67	04.17	04.43	21.63
	Tirupati	04.37	05.25	04.58	00.87	16.65	− 00.67	− 14.52
	Visakhapatnam	08.23	07.79	08.56	− 00.44	− 05.67	00.76	08.93
	Rajahmundry	09.49	09.25	09.07	− 00.24	− 02.63	− 00.18	− 01.94
2019								
Maharashtra								
$PM_{2.5}$	Chandrapur	51.37	40.74	52.64	− 10.63	− 26.10	11.90	22.60
	Mumbai	77.47	94.22	98.09	16.75	17.78	03.87	03.95
	Nagpur	42.13	35.45	48.15	− 06.69	− 18.86	12.70	26.39
	Solapur	47.99	43.35	38.45	− 04.64	− 10.70	− 04.90	− 12.74
	Navi Mumbai	89.41	106.86	108.8	17.45	16.33	01.91	01.76
PM_{10}	Chandrapur	91.83	72.39	84.30	− 19.45	− 26.86	11.91	14.13
	Mumbai	138.33	165.36	164.68	27.03	16.35	− 00.68	− 00.41
	Nagpur	80.04	71.64	87.94	− 08.40	− 11.72	16.30	18.53
	Solapur	131.68	78.75	107.51	− 52.93	− 67.21	28.76	26.75
	Navi Mumbai	170.23	176.88	170.07	06.65	03.76	− 06.81	− 04.00
NO_2	Chandrapur	09.28	08.21	09.70	− 01.07	− 13.07	01.50	15.42
	Mumbai	33.50	33.11	37.74	− 00.39	− 01.19	04.63	12.27
	Nagpur	45.49	45.13	45.11	− 00.36	− 00.81	− 00.02	− 00.04
	Solapur	69.28	51.25	31.34	− 18.03	− 35.17	− 19.91	− 63.54
	Navi Mumbai	53.99	56.25	49.17	02.26	04.02	− 07.08	− 14.39
SO_2	Chandrapur	09.71	06.39	05.85	− 03.32	− 51.95	− 00.54	− 09.26
	Mumbai	10.89	09.14	07.93	− 01.76	− 19.23	− 01.21	− 15.21
	Nagpur	08.64	09.32	09.79	00.69	07.37	00.47	04.80
	Solapur	12.43	13.22	14.58	00.79	05.97	01.36	09.36
	Navi Mumbai	16.91	20.92	16.41	04.01	19.18	− 04.51	− 27.48

Table 2 (continued)

Pollutants	Cities	Dec 1–23	Dec 24–Jan 1	Jan 1–4	Pre-festival		Post-festival	
					Net variance	%	Net variance	%
2019								
Punjab								
$PM_{2.5}$	Ludhiana	67.58	72.33	55.92	04.74	06.56	− 16.41	− 29.34
	Mandi	126.1	97.25	129.6	− 28.91	− 29.72	32.30	24.93
	Amritsar	66.71	75.71	84.71	09.00	11.88	9.00	10.63
	Patiala	74.76	79.70	67.78	04.94	06.19	− 11.91	− 17.57
	Khanna	73.35	59.86	66.80	− 13.49	− 22.54	6.94	10.39
	Bathinda	49.16	78.24	60.56	29.07	37.16	− 17.67	− 29.18
PM_{10}	Ludhiana	129.9	147.5	119.9	17.59	11.92	− 27.55	− 22.96
	Mandi	179.6	131.3	176.9	− 48.31	− 36.80	45.65	25.80
	Amritsar	98.61	104.5	119.1	05.85	05.60	14.68	12.32
	Patiala	135.8	142.9	133.43	07.10	04.97	− 09.44	− 07.07
	Khanna	159.5	149.6	166.9	− 09.85	− 06.58	17.34	10.39
	Bathinda	174.5	131.5	103.5	− 42.99	− 32.69	− 27.97	− 27.02
NO_2	Ludhiana	21.41	23.72	32.77	02.32	09.77	09.05	27.60
	Mandi	14.31	10.13	09.90	− 04.18	− 41.22	− 00.23	− 02.36
	Amritsar	12.45	10.50	10.15	− 01.95	− 18.53	− 00.36	− 03.53
	Patiala	18.12	17.33	17.69	− 00.79	− 04.56	00.36	02.05
	Khanna	14.60	8.22	10.38	− 06.38	− 77.56	02.16	20.79
	Bathinda	18.20	18.22	18.25	00.02	00.11	00.03	00.15
SO_2	Ludhiana	07.04	09.01	6.23	01.97	21.87	− 02.78	− 44.65
	Mandi	14.41	06.60	23.73	− 07.81	− 118.34	17.14	72.20
	Amritsar	08.78	9.45	10.60	00.67	07.14	01.14	10.78
	Patiala	18.48	15.78	15.15	− 02.70	− 17.13	− 00.63	− 04.13
	Khanna	30.18	14.36	20.25	− 15.82	− 110.11	05.89	29.06
	Bathinda	07.12	07.61	7.77	00.49	06.46	00.16	02.00
2019								
Madhya Pradesh								
$PM_{2.5}$	Bhopal	87.06	80.80	87.16	− 06.26	− 07.75	06.36	07.29
	Indore	77.64	66.68	83.58	− 10.95	− 16.42	16.90	20.21
	Ratlam	51.57	58.19	79.80	06.62	11.38	21.61	27.08
	Dewas	66.60	62.91	72.77	− 03.69	− 05.87	09.86	13.55
	Jabalpur	88.49	102.0	118.5	13.55	13.27	16.47	13.90
PM_{10}	Bhopal	164.0	133.5	141.9	− 30.55	− 22.89	08.47	05.97
	Indore	143.7	116.4	142.5	− 27.24	− 23.39	26.05	18.28
	Ratlam	141.5	140.6	173.9	− 00.88	− 00.62	33.33	19.17
	Dewas	124.2	101.2	113.5	− 23.01	− 22.73	12.29	10.83
	Jabalpur	194.9	204.7	233.1	09.75	04.76	28.40	12.18
NO_2	Bhopal	54.75	46.41	44.03	− 08.33	− 17.96	− 02.39	− 05.42
	Indore	58.87	55.54	51.80	− 03.33	− 05.99	− 03.74	− 07.23
	Ratlam	30.92	51.91	47.84	20.99	40.43	− 04.08	− 08.52
	Dewas	31.00	23.82	19.14	− 07.18	− 30.15	− 04.67	− 24.41
	Jabalpur	45.98	45.46	48.40	− 00.52	− 01.14	02.94	06.07

Table 2 (continued)

Pollutants	Cities	Dec 1–23	Dec 24–Jan 1	Jan 1–4	Pre-festival		Post-festival	
					Net variance	%	Net variance	%
SO_2	Bhopal	12.89	07.78	05.59	− 05.11	− 65.73	− 02.19	− 39.16
	Indore	10.05	09.68	07.11	− 00.36	− 03.76	− 02.58	− 36.26
	Ratlam	06.64	03.06	02.91	− 03.58	− 117.27	− 00.15	− 05.16
	Dewas	12.08	13.09	07.95	01.02	07.76	− 05.15	− 64.77
	Jabalpur	15.27	12.76	13.58	− 02.50	− 19.60	00.82	06.01
2019								
Rajasthan								
$PM_{2.5}$	Ajmer	50.82	56.21	74.98	5.39	9.59	18.77	25.04
	Bhilwara	142.79	176.90	203.28	34.11	19.28	26.38	12.98
	Jodhpur	79.34	86.75	111.88	7.41	8.54	25.13	22.46
	Kota	66.15	69.51	75.85	3.36	4.83	6.33	8.35
	Udaipur	53.80	73.40	69.88	19.60	26.70	− 3.52	− 5.04
PM_{10}	Ajmer	106.00	108.27	142.37	2.27	2.09	34.11	23.96
	Bhilwara	266.67	321.95	383.11	55.28	17.17	61.16	15.96
	Jodhpur	163.05	175.89	204.82	12.83	7.30	28.93	14.13
	Kota	133.53	146.75	146.72	13.22	9.01	− 0.03	− 0.02
	Udaipur	108.53	149.72	130.42	41.19	27.51	− 19.31	− 14.80
NO_2	Ajmer	33.13	30.67	32.43	− 2.46	− 8.01	1.76	5.41
	Bhilwara	47.75	31.68	34.86	− 16.06	− 50.70	3.17	9.11
	Jodhpur	18.50	24.00	23.05	5.50	22.93	− 0.95	− 4.11
	Kota	59.75	28.44	30.82	− 31.31	− 110.09	2.38	7.71
	Udaipur	22.15	30.93	25.86	8.78	28.40	− 5.07	− 19.62
SO_2	Ajmer	5.95	7.34	8.47	1.38	18.82	1.14	13.43
	Bhilwara	31.03	22.58	31.34	− 8.44	− 37.39	8.75	27.93
	Jodhpur	7.34	7.49	7.51	0.16	2.10	0.02	0.28
	Kota	8.78	8.45	8.49	− 0.32	− 3.82	0.03	0.39
	Udaipur	10.00	12.81	6.67	2.81	21.92	− 6.14	− 91.94
2020								
Andhra Pradesh								
PM2.5	Amaravati	69.58	111.71	92.29	42.13	37.72	− 19.42	− 21.04
	Tirupati	36.66	70.98	47.17	34.32	48.35	− 23.81	− 50.48
	Visakhapatnam	84.87	127.27	101.88	42.40	33.31	− 25.39	− 24.92
	Rajahmundry	67.41	103.64	96.47	36.23	34.96	− 7.17	− 7.43
PM10	Amaravati	108.27	162.93	136.71	54.66	33.55	− 26.23	− 19.18
	Tirupati	52.82	96.04	67.77	43.22	45.00	− 28.27	− 41.71
	Visakhapatnam	175.72	248.47	185.38	72.75	29.28	− 63.09	− 34.03
	Rajahmundry	127.92	171.13	157.14	43.21	25.25	− 13.99	− 8.90
NO2	Amaravati	21.38	23.02	18.94	1.64	7.14	− 4.08	− 21.52
	Tirupati	27.09	34.19	30.72	7.10	20.76	− 3.46	− 11.28
	Visakhapatnam	26.03	34.72	41.32	8.69	25.02	6.60	15.98
	Rajahmundry	22.14	21.81	19.42	− 0.33	− 1.49	− 2.39	− 12.33
SO2	Amaravati	14.91	20.51	14.76	5.60	27.31	− 5.75	− 38.99
	Tirupati	6.28	6.39	7.34	0.11	1.72	0.95	12.95
	Visakhapatnam	14.34	11.90	6.89	− 2.44	− 20.52	− 5.01	− 72.65
	Rajahmundry	15.83	17.03	13.91	1.20	7.06	− 3.12	− 22.45

Table 2 (continued)

Pollutants	Cities	Dec 1–23	Dec 24–Jan 1	Jan 1–4	Pre-festival		Post-festival	
					Net variance	%	Net variance	%
2020								
Maharashtra								
$PM_{2.5}$	Chandrapur	44.11	54.51	56.76	10.40	19.08	2.25	3.96
	Mumbai	63.64	85.66	113.32	22.02	25.71	27.66	24.41
	Nagpur	42.25	42.24	53.70	− 0.01	− 0.02	11.46	21.34
	Solapur	49.46	71.73	70.46	22.27	31.05	− 1.27	− 1.80
	Navi Mumbai	86.72	109.40	149.26	22.68	20.73	39.86	26.70
PM_{10}	Chandrapur	140.41	162.46	154.52	22.05	13.57	− 7.94	− 5.14
	Mumbai	115.73	162.24	183.10	46.51	28.67	20.86	11.39
	Nagpur	71.99	39.95	30.78	− 32.04	− 80.21	− 9.17	− 29.80
	Solapur	122.76	155.05	149.67	32.29	20.83	− 5.38	− 3.60
	Navi Mumbai	151.42	210.30	230.56	58.89	28.00	20.25	8.78
NO_2	Chandrapur	18.80	21.71	16.69	2.91	13.42	− 5.02	− 30.10
	Mumbai	31.22	37.55	40.79	6.33	16.86	3.24	7.94
	Nagpur	40.33	42.32	47.07	2.00	4.71	4.75	10.08
	Solapur	16.61	31.19	28.29	14.58	46.76	− 2.90	− 10.25
	Navi Mumbai	55.00	92.55	70.71	37.55	40.57	− 21.83	− 30.88
SO_2	Chandrapur	21.76	23.14	17.16	1.37	5.93	− 5.98	− 34.84
	Mumbai	9.63	9.41	9.61	− 0.22	− 2.34	0.20	2.11
	Nagpur	1.57	0.91	0.61	− 0.66	− 73.16	− 0.30	− 48.63
	Solapur	4.70	9.60	9.61	4.90	51.01	0.01	0.15
	Navi Mumbai	18.84	11.45	6.12	− 7.39	− 64.51	− 5.34	− 87.23
2020								
Punjab								
$PM_{2.5}$	Ludhiana	73.41	63.09	61.53	− 10.31	− 16.35	− 1.56	− 2.53
	Mandi	81.61	71.05	47.81	129.55	− 14.86	− 23.25	− 48.63
	Amritsar	66.45	65.93	42.20	− 0.52	− 0.78	− 23.73	− 56.24
	Patiala	65.11	69.07	58.61	3.96	5.74	− 10.47	− 17.86
	Khanna	66.79	58.98	60.86	− 7.81	− 13.24	1.88	3.09
	Bathinda	53.14	80.30	87.35	27.16	33.82	7.05	8.07
PM_{10}	Ludhiana	149.87	127.41	120.74	− 22.46	− 17.63	− 6.67	− 5.52
	Mandi	178.00	159.25	105.79	176.93	− 11.78	− 53.46	− 50.54
	Amritsar	122.00	130.10	74.57	8.10	6.23	− 55.53	− 74.46
	Patiala	143.28	149.02	118.25	5.74	3.85	− 30.77	− 26.02
	Khanna	140.42	137.58	114.99	− 2.83	− 2.06	− 22.60	− 19.65
	Bathinda	157.03	171.37	142.46	14.34	8.37	− 28.91	− 20.30
NO_2	Ludhiana	26.99	19.31	14.54	− 7.68	− 39.77	− 4.77	− 32.83
	Mandi	19.25	11.36	11.37	9.90	− 89.42	0.01	0.05
	Amritsar	24.90	32.07	32.17	7.17	22.35	0.10	0.31
	Patiala	19.74	28.64	28.09	8.90	31.08	− 0.55	− 1.95
	Khanna	29.11	26.62	22.87	− 2.49	− 9.35	− 3.75	− 16.39
	Bathinda	24.25	24.26	24.45	0.01	0.03	0.19	0.77

Table 2 (continued)

Pollutants	Cities	Dec 1–23	Dec 24–Jan 1	Jan 1–4	Pre-festival		Post-festival	
					Net variance	%	Net variance	%
SO_2	Ludhiana	5.90	6.83	8.82	0.93	13.60	1.99	22.55
	Mandi	14.88	16.78	7.73	23.73	11.35	− 9.05	− 117.00
	Amritsar	5.63	7.18	14.38	1.55	21.62	7.21	50.10
	Patiala	7.10	8.23	9.92	1.14	13.81	1.69	17.04
	Khanna	10.02	5.87	8.36	− 4.15	− 70.60	2.48	29.73
	Bathinda	7.03	7.17	7.12	0.14	1.94	− 0.04	− 0.62
2020								
Madhya Pradesh								
$PM_{2.5}$	Bhopal	66.83	81.95	146.05	15.12	18.45	64.10	43.89
	Indore	69.63	75.37	101.25	5.74	7.62	25.88	25.56
	Ratlam	47.58	55.66	98.17	8.08	14.52	42.51	43.30
	Dewas	47.90	68.46	101.27	20.56	30.04	32.81	32.40
	Jabalpur	105.60	110.35	72.54	4.75	4.31	− 37.82	− 52.14
PM_{10}	Bhopal	147.27	185.63	250.72	38.36	20.67	65.10	25.96
	Indore	137.42	157.00	161.45	19.58	12.47	4.45	2.76
	Ratlam	126.21	146.75	156.42	20.54	14.00	9.67	6.18
	Dewas	97.36	154.65	144.51	57.29	37.04	− 10.14	− 7.01
	Jabalpur	189.88	179.03	126.30	− 10.85	− 8.06	− 52.73	− 41.75
NO_2	Bhopal	49.22	42.79	51.60	− 8.43	− 15.03	8.81	17.08
	Indore	53.56	48.18	40.61	− 5.38	− 11.17	− 7.57	− 18.64
	Ratlam	55.09	50.60	43.08	− 4.49	− 8.88	− 7.52	− 17.44
	Dewas	30.88	28.15	21.23	− 2.73	− 9.72	− 8.92	− 32.61
	Jabalpur	48.35	54.17	45.92	5.82	10.74	− 8.25	− 17.97
SO_2	Bhopal	16.96	22.68	31.59	5.72	25.24	8.91	28.19
	Indore	11.17	16.35	20.68	5.19	31.71	4.33	20.93
	Ratlam	6.79	14.64	29.58	7.84	53.59	14.94	50.52
	Dewas	9.30	10.47	10.53	1.17	11.19	0.05	0.52
	Jabalpur	11.49	12.55	6.02	1.06	8.46	− 8.53	− 108.54
2020								
Rajasthan								
$PM_{2.5}$	Ajmer	47.04	64.72	75.82	17.67	27.31	11.10	14.65
	Bhilwara	72.87	75.35	85.56	2.48	3.28	10.21	11.93
	Jodhpur	82.94	92.67	117.88	9.73	10.50	25.21	21.39
	Kota	68.72	88.21	95.09	19.49	22.10	6.88	7.23
	Udaipur	68.02	83.57	109.58	15.55	18.61	26.01	23.74
PM_{10}	Ajmer	99.20	125.60	148.31	26.40	21.02	22.71	15.31
	Bhilwara	156.74	154.89	150.06	− 1.86	− 1.20	− 4.83	− 3.22
	Jodhpur	172.12	182.15	253.52	10.03	5.51	71.37	28.15
	Kota	123.80	175.92	152.62	52.11	29.62	− 23.30	− 15.26
	Udaipur	133.97	151.62	168.73	17.65	11.64	17.11	10.14
NO_2	Ajmer	35.69	29.81	27.96	− 5.88	− 19.71	− 1.85	− 8.62
	Bhilwara	69.37	74.89	61.41	5.52	7.37	− 13.48	− 21.95
	Jodhpur	33.74	28.06	23.06	− 5.69	− 20.26	− 5.00	− 21.68
	Kota	24.62	27.08	24.57	2.46	9.09	− 2.51	− 10.23
	Udaipur	22.84	28.68	63.00	5.84	20.36	34.32	54.48

Table 2 (continued)

Pollutants	Cities	Dec 1–23	Dec 24–Jan 1	Jan 1–4	Pre-festival		Post-festival	
					Net variance	%	Net variance	%
SO_2	Ajmer	7.02	5.86	3.98	− 1.17	− 19.90	− 1.88	− 47.25
	Bhilwara	11.96	13.62	9.73	1.66	12.17	− 3.89	− 40.03
	Jodhpur	11.74	10.65	9.93	− 1.09	− 10.22	− 0.72	− 7.30
	Kota	9.56	9.52	9.55	− 0.03	− 0.37	0.03	0.27
	Udaipur	14.47	20.15	27.95	5.68	28.19	7.80	27.91
2021								
Andhra Pradesh								
$PM_{2.5}$	Amaravati	58.74	71.33	68.17	12.59	17.65	− 3.16	− 4.64
	Tirupati	54.70	43.50	49.77	− 11.20	− 25.75	6.27	12.60
	Visakhapatnam	58.63	64.20	68.53	5.57	8.68	4.33	6.32
	Rajahmundry	58.71	67.37	71.95	8.66	12.85	4.58	6.36
PM_{10}	Amaravati	91.70	98.20	92.92	6.50	6.62	− 5.28	− 5.68
	Tirupati	69.38	60.00	62.46	− 9.37	− 15.62	2.46	3.94
	Visakhapatnam	116.01	127.28	117.09	11.28	8.86	− 10.19	− 8.70
	Rajahmundry	103.67	116.82	121.69	13.14	11.25	4.88	4.01
NO_2	Amaravati	17.07	14.94	13.68	− 2.13	− 14.25	− 1.26	− 9.25
	Tirupati	17.49	17.94	15.25	0.44	2.47	− 2.69	− 17.64
	Visakhapatnam	36.15	40.41	31.53	4.26	10.55	− 8.88	− 28.16
	Rajahmundry	21.09	22.71	20.92	1.62	7.15	− 1.80	− 8.58
SO_2	Amaravati	17.70	12.69	16.42	− 5.01	− 39.49	3.73	22.72
	Tirupati	5.84	6.49	5.44	0.65	10.05	− 1.05	− 19.37
	Visakhapatnam	16.59	14.23	21.96	− 2.35	− 16.53	7.72	35.18
	Rajahmundry	13.50	7.55	12.41	− 5.96	− 78.93	4.87	39.21
2021								
Maharashtra								
$PM_{2.5}$	Chandrapur	77.54	65.57	63.10	− 11.97	− 18.25	− 2.47	− 3.91
	Mumbai	77.96	61.79	59.74	− 16.16	− 26.15	− 2.05	− 3.43
	Nagpur	74.38	39.37	36.55	− 35.00	− 88.89	− 2.82	− 7.73
	Solapur	48.99	46.20	36.08	− 2.79	− 8.03	− 10.12	− 28.06
	Navi Mumbai	87.27	97.40	97.80	10.13	10.40	0.40	0.41
PM_{10}	Chandrapur	150.24	117.64	115.87	− 32.60	− 27.71	− 1.77	− 1.53
	Mumbai	164.19	159.81	168.05	− 4.38	− 2.74	8.24	4.90
	Nagpur	94.33	89.07	80.53	− 5.26	− 5.90	− 8.54	− 10.60
	Solapur	83.81	77.79	62.42	− 8.03	− 7.75	− 15.37	− 24.62
	Navi Mumbai	123.79	130.66	136.55	6.87	5.26	5.89	4.31
NO_2	Chandrapur	25.07	14.50	20.96	− 10.57	− 72.88	6.46	30.80
	Mumbai	31.47	30.02	29.99	− 1.45	− 4.84	− 0.03	− 0.10
	Nagpur	27.26	27.26	27.21	0.00	0.02	− 0.05	− 0.19
	Solapur	40.79	39.94	40.09	− 0.84	− 2.12	0.14	0.36
	Navi Mumbai	37.28	37.16	46.29	− 0.12	− 0.32	9.13	19.73
SO_2	Chandrapur	26.96	25.87	25.11	− 1.09	− 4.22	− 0.76	− 3.01
	Mumbai	9.17	7.29	7.87	− 1.87	− 25.70	0.58	7.39
	Nagpur	14.13	13.04	14.42	− 1.08	− 8.31	1.37	9.52
	Solapur	16.88	19.30	18.25	2.42	12.52	− 1.05	− 5.73
	Navi Mumbai	24.09	47.96	52.37	23.87	49.77	4.41	8.42

Table 2 (continued)

Pollutants	Cities	Dec 1–23	Dec 24–Jan 1	Jan 1–4	Pre-festival		Post-festival	
					Net variance	%	Net variance	%
2021								
Punjab								
$PM_{2.5}$	Ludhiana	88.40	88.64	63.57	0.23	0.26	− 25.07	− 39.44
	Mandi	67.57	116.84	105.04	49.27	42.17	− 11.80	− 11.23
	Amritsar	76.72	66.00	48.33	− 10.72	− 16.24	− 17.67	− 36.56
	Patiala	88.52	79.28	88.86	− 9.24	− 11.66	9.58	10.78
	Khanna	80.08	82.37	100.80	2.29	2.79	18.43	18.28
	Bathinda	54.74	77.15	63.21	22.41	29.05	− 13.94	− 22.06
PM_{10}	Ludhiana	174.37	183.31	145.44	8.94	4.88	− 37.87	− 26.04
	Mandi	154.99	215.95	209.57	60.96	28.23	− 8.38	− 3.05
	Amritsar	167.48	155.12	136.00	− 12.37	− 7.97	− 19.12	− 14.06
	Patiala	176.57	169.87	180.82	− 8.71	− 3.95	10.95	6.06
	Khanna	147.46	152.95	176.55	5.49	3.59	23.60	13.37
	Bathinda	227.98	177.79	138.79	− 50.20	− 28.23	− 39.00	− 28.10
NO_2	Ludhiana	31.43	29.53	30.23	− 1.91	− 8.46	0.70	2.32
	Mandi	17.04	23.14	23.15	6.10	26.34	0.01	0.03
	Amritsar	14.64	20.74	21.47	6.10	29.41	0.73	3.40
	Patiala	20.57	16.34	16.89	− 4.23	− 25.86	0.54	3.22
	Khanna	37.40	23.11	22.97	− 14.30	− 81.87	− 0.14	− 0.61
	Bathinda	13.04	13.32	13.27	0.29	2.16	− 0.05	− 0.38
SO_2	Ludhiana	23.89	19.29	15.96	− 4.61	− 23.88	− 3.33	− 20.86
	Mandi	7.76	12.63	22.94	4.87	38.57	10.32	44.97
	Amritsar	11.80	12.88	12.75	1.08	8.40	− 0.13	− 1.00
	Patiala	4.22	3.85	4.81	− 0.37	− 9.72	0.96	20.01
	Khanna	20.69	17.68	17.65	− 3.01	− 17.03	− 0.02	− 0.13
	Bathinda	7.04	6.76	6.78	− 0.28	− 4.14	0.03	0.39
2021								
Madhya Pradesh								
$PM_{2.5}$	Bhopal	87.10	84.55	74.44	− 2.56	− 3.03	− 10.10	− 13.57
	Indore	87.48	74.32	60.37	− 13.16	− 17.71	− 13.95	− 23.10
	Ratlam	47.46	47.76	21.24	0.30	0.62	− 26.52	− 124.86
	Dewas	55.12	71.98	53.95	16.86	23.42	− 18.03	− 33.43
	Jabalpur	106.6	136.5	130.9	30.0	22.0	− 5.6	− 4.3
PM_{10}	Bhopal	166.79	149.51	136.76	− 17.29	− 11.56	− 12.75	− 9.32
	Indore	154.03	129.47	107.88	− 24.56	− 18.97	− 21.59	− 20.01
	Ratlam	108.99	109.27	43.24	0.28	0.26	− 86.04	− 152.74
	Dewas	110.22	111.29	85.10	1.06	0.95	− 26.19	− 30.77
	Jabalpur	245.6	255.3	232.2	9.7	3.8	− 23.1	− 9.9
NO_2	Bhopal	28.46	37.31	35.33	8.85	23.72	− 1.98	− 5.61
	Indore	78.05	66.28	58.99	− 11.77	− 17.75	− 7.29	− 12.36
	Ratlam	36.82	39.70	27.07	2.88	7.26	− 12.64	− 46.70
	Dewas	23.69	20.71	16.62	− 2.98	− 14.37	− 4.09	− 24.60
	Jabalpur	67.6	65.3	63.7	− 2.3	− 3.5	− 1.6	− 2.6

Table 2 (continued)

Pollutants	Cities	Dec 1–23	Dec 24–Jan 1	Jan 1–4	Pre-festival		Post-festival	
					Net variance	%	Net variance	%
SO_2	Bhopal	23.22	23.22	27.49	0.00	0.00	4.27	15.53
	Indore	14.87	15.76	12.86	0.89	5.65	− 2.90	− 22.58
	Ratlam	12.67	10.99	5.97	− 1.68	− 15.30	− 5.02	− 84.20
	Dewas	10.55	10.36	9.80	− 0.19	− 1.81	− 0.56	− 5.73
	Jabalpur	14.0	14.9	21.1	0.8	5.5	6.2	29.5
2021								
Rajasthan								
$PM_{2.5}$	Ajmer	49.41	62.40	60.02	12.99	20.82	− 2.38	− 3.96
	Bhilwara	75.07	92.88	109.99	17.81	19.17	17.11	15.55
	Jodhpur	93.09	71.55	96.22	− 21.54	− 30.10	24.67	25.64
	Kota	96.73	102.79	112.55	6.06	5.90	9.76	8.67
	Udaipur	81.42	73.35	98.57	− 8.07	− 11.00	25.22	25.59
PM_{10}	Ajmer	103.80	126.91	128.14	23.11	18.21	1.23	0.96
	Bhilwara	156.69	163.09	226.72	6.40	3.92	63.63	28.07
	Jodhpur	183.30	164.50	214.14	− 18.80	− 11.43	49.64	23.18
	Kota	142.05	145.38	183.08	3.33	2.29	37.70	20.59
	Udaipur	147.43	153.43	186.18	6.00	3.91	32.75	17.59
NO_2	Ajmer	30.67	26.24	31.54	− 4.43	− 16.90	5.31	16.82
	Bhilwara	70.18	61.79	71.02	− 8.39	− 13.58	9.23	13.00
	Jodhpur	51.42	42.01	55.10	− 9.41	− 22.39	13.09	23.76
	Kota	25.04	25.95	34.86	0.91	3.52	8.92	25.57
	Udaipur	38.87	25.05	22.99	− 13.82	− 55.16	− 2.06	− 8.98
SO_2	Ajmer	14.87	13.83	8.76	− 1.04	− 7.48	− 5.07	− 57.91
	Bhilwara	10.15	12.48	12.66	2.33	18.64	0.19	1.47
	Jodhpur	9.45	9.18	10.21	− 0.26	− 2.87	1.03	10.07
	Kota	10.28	9.75	9.94	− 0.53	− 5.39	0.19	1.93
	Udaipur	13.98	9.62	9.61	− 4.36	− 45.37	− 0.01	− 0.13

3 Results and discussion

3.1 Air pollutants concentration profile in Christmas and new year celebration in 2019, 2020 and 2021

The average pollutant concentration of each state during the festive period i.e., 24th December to 1st January, is based on the station data, which was taken by the availability for 5–6 cities for three consecutive years 2019, 2020, and 2021 (Table 1). India faced a national lockdown on 24th March 2020 due to the spread of the COVID-19 virus, followed by four lockdown periods. In Madhya Pradesh 2019, $PM_{2.5}$ and PM_{10} were beyond the permissible limit during the festive time. A drastic decrease in pollutant concentration is seen for 2020 and 2021. Irrespective of lockdowns, SO_2 and NO_2 were seen below the permissible limits before 2020 and 2021 and seemed to be increased by 11% and 24%. As for Rajasthan, SO_2 and NO_2 were less than the threshold limit in 2019 but eventually increased in 2020 and 2021; a near increase in PM_{10} is also observed. Andhra Pradesh had no effective increase in pollutants during Christmas and the new year, and pollutants remain in the permissible limit, and $PM_{2.5}$ seems to be nearly high for 2020 and lesser for the year 2021. $PM_{2.5}$ has increased from 2019 to 2021 for Punjab compared, which is also seen with PM_{10}. NO_2 and SO_2 remain below the limit throughout the year 2019. In 2020 Punjab experienced a decrease in the pollutant values but an increase in 2021. It was observed in Maharashtra a decrease in $PM_{2.5}$, PM_{10}, NO_2, and SO_2 when compared between 2019 and 2021. A sudden increase was seen in some pollutants in 2021; the reason may be the lifting of the lockdowns and not having strict restrictions, which may have facilitated

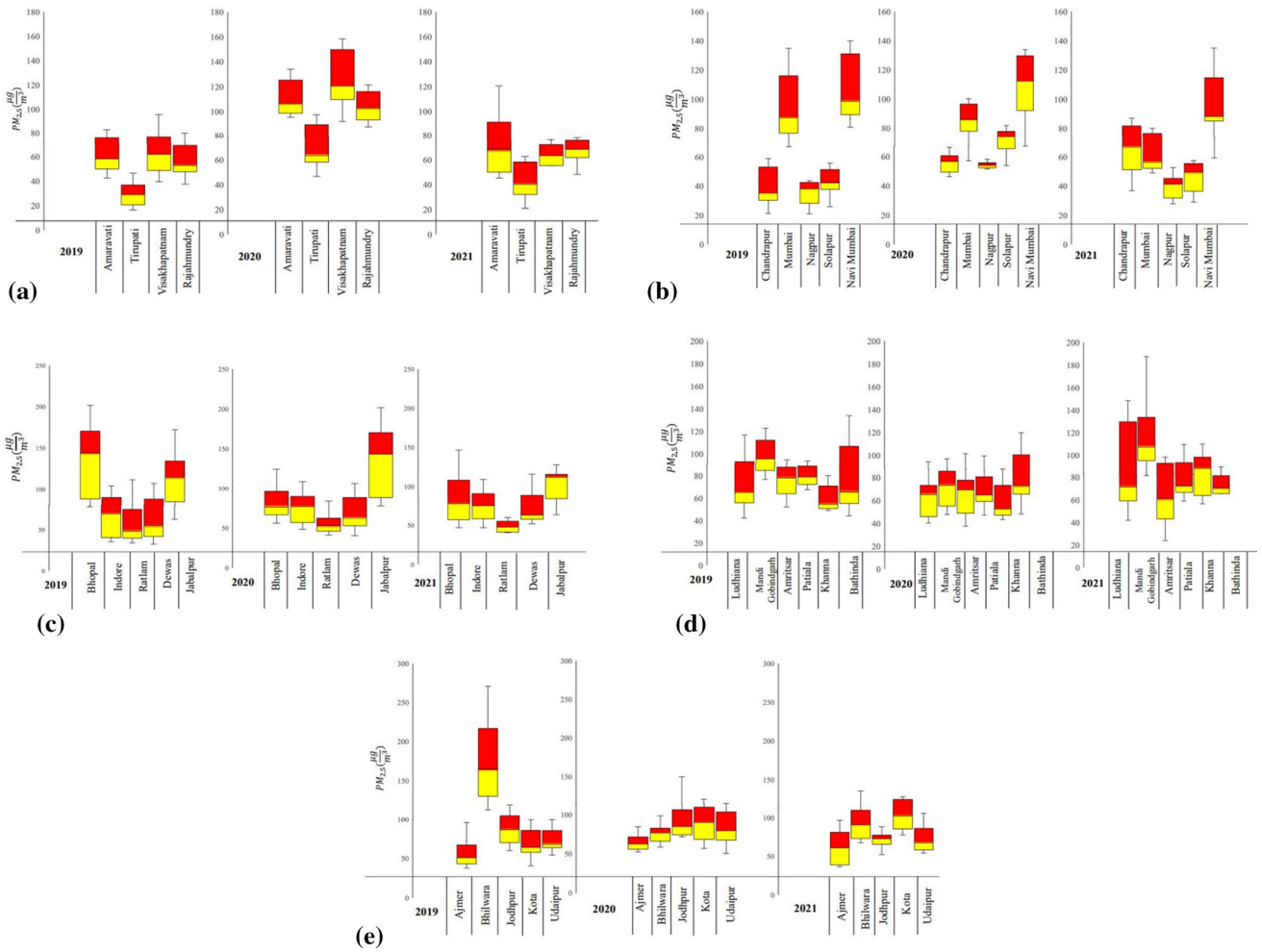

Fig. 2 The box plot showing the concentrations of $PM_{2.5}$ at various cities of Indian states like **a** Andhra Pradesh, **b** Maharashtra, **c** Madhya Pradesh, **d** Punjab, and **e** Rajasthan on pre, during, and post days of Christmas and New Year Celebration in three consecutive years (2019, 2020 and 2021)

the transportations and gatherings and fireworks, which increases the PM loads. The increased PM concentrations can be a solid medium to spread COVID-19 (Table 2).

The Figs. 2–3 represents the air pollutants during the Christmas and New year of 2019, 2020, and 2021. The statistical measures like maximum, median, minimum, first, and third quartiles are seen. Figure 2a–e represents the $PM_{2.5}$, Fig. 4a–e shows PM_{10}, Fig. 5a–e, and Fig. 3a–e represent SO_2 and NO_2 concentrations. The state-wise description of the boxplots for the pollutants obtained are $PM_{2.5}$ for Amaravati, Tirupati, and Vishakhapatnam seemed to increase between Christmas and the new year for 2019 and 2021 and decrease in 2020, whereas $PM_{2.5}$ for Rajahmundry was lesser in 2019 and increased for the following years. PM_{10} as less in 2019 for the five cities only Tirupati seemed higher. In 2020 the PM_{10} values were lesser than in 2019; surprisingly, Vishakhapatnam was higher. There is a decrease in the PM_{10} concentration, yet Amaravati and Vishakhapatnam have higher values than the remaining cities. NO_2 values for Amravati have been lesser for all 3 years, Tirupati and Rajahmundry had a varied rise, and Vishakhapatnam showed increased NO_2 values. SO_2 values increased from 2019 and 2021. As in 2020, SO_2 values were relatively more minor. $PM_{2.5}$ and SO_2 values for Chandrapur, Mumbai, and Solapur have been elevated, whereas the values for Navi Mumbai have significantly unnoticeable higher values. PM_{10} and NO_2 statistical values for the five cities are seen lesser when compared to Navi Mumbai for the year 2020. SO_2 values have been increased. NO_2 values during Christmas and new year for 2020 were less and later increased in 2021. NO_2 in Jabalpur was less, whereas Indore showed higher statistical values. $PM_{2.5}$ for all the four cities in Madhya Pradesh has been decreased for 2020, but are slightly seen increasing in 2021, expect Jabalpur in the year of 2020, $PM_{2.5}$ has been decreased for the year of 2021. PM_{10} has decreased when compared to 2019 and 2020.SO_2 values

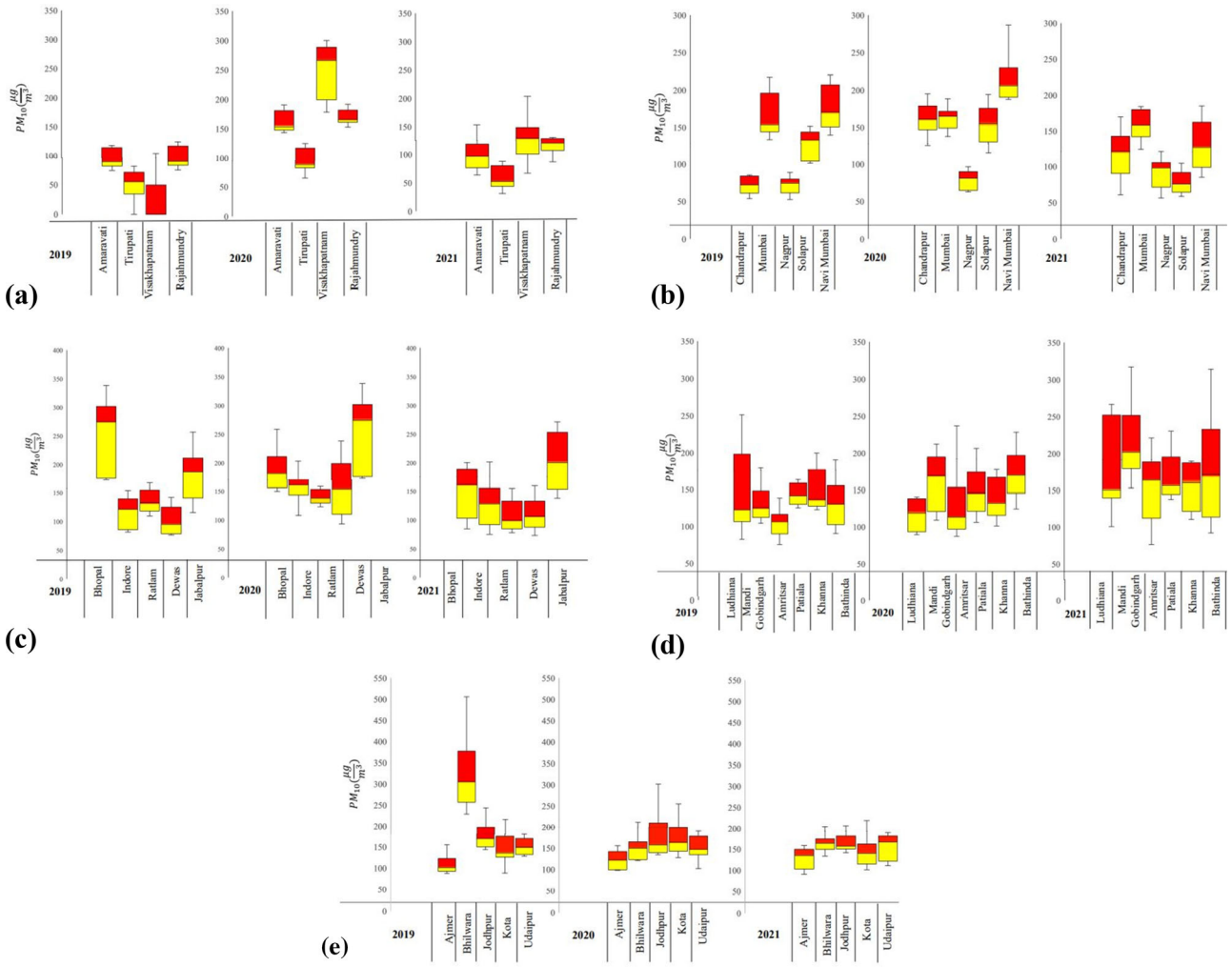

Fig. 4 The box plot showing the concentrations of PM_{10} at various cities of Indian states like **a** Andhra Pradesh, **b** Maharashtra, **c** Madhya Pradesh, **d** Punjab, and **e** Rajasthan on pre, during, and post days of Christmas and New Year Celebration in three consecutive years (2019, 2020 and 2021)

also decreased, but only for Bhopal; there is an increase for 2021.

$PM_{2.5}$ and PM_{10} for the cities in Punjab were seen to decrease in the year 2020 compared to 2021. Ludhiana and Mandi Gobindgarh have higher $PM_{2.5}$ values for 2021. NO_2 and SO_2 values have decreased from 2019. Rajasthan observed a decrease in the $PM_{2.5}$, PM_{10}, and SO_2 values during Christmas and the new year. NO_2 values have been increased, especially in Bhilwara for 2020 compared with 2021.

3.2 Variation in air pollutant concentration profile

The below tables explain the changes detected in air pollutant concentrations during the years 2019, 2020 and 2021. The $PM_{2.5}$ of Andhra Pradesh experienced an increase during the festival season of years 2019 and 2020, while in the year 2021, it had a decrease during the festival rather than pre-festive and post-festive days. This increase in $PM_{2.5}$ can cause shortness of breath and lung irritations, increasing the chances of getting affected to COVID-19. Surprisingly the PM_{10} concentrations elevated in 2020 and 2021 in Andhra Pradesh during the festive time. In 2019 PM_{10}, decreased gradually during the post-festive period, which is similarly seen with NO_2 levels of all 3 years for Andhra Pradesh. In 2021, the SO_2 was seen to increase in post-festive days, probably due to the increase in vehicle movement (burning of fossil fuels). This may cause throat irritations, coughing, mucus secretion, and other respiratory problems, indirectly increasing the risk of asymptomatic COVID-positive patients quarantined at home. During the pre-festive days, Maharashtra had recorded the highest levels of NO_2 during 2019, whereas $PM_{2.5}$ PM_{10} recorded the highest during the year 2020. The NO_2 and SO_2 value for the year 2021, during the festive period,

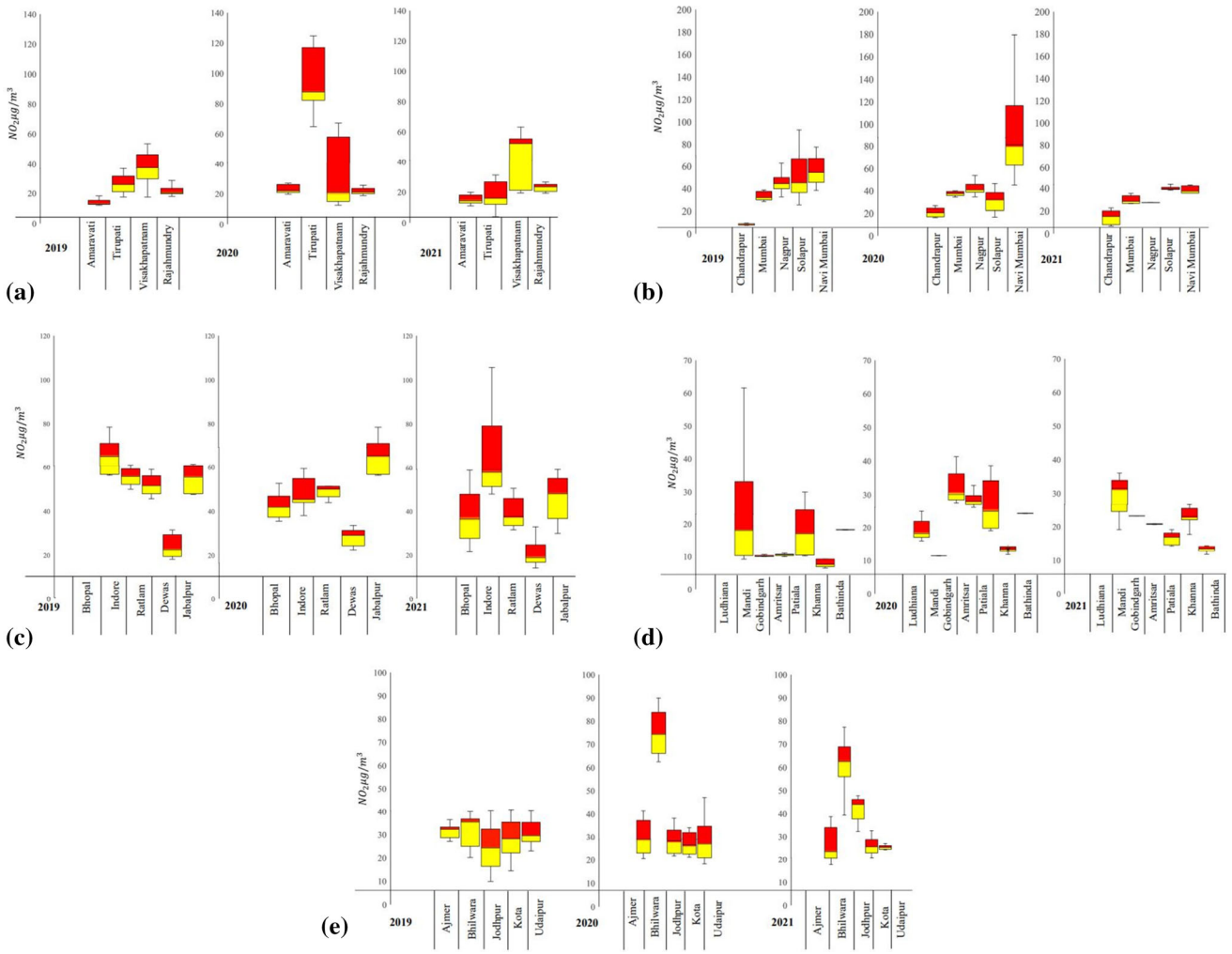

Fig. 5 The box plot showing the concentrations of NO_2 at various cities of Indian states like **a** Andhra Pradesh, **b** Maharashtra, **c** Madhya Pradesh, **d** Punjab, and **e** Rajasthan on pre, during, and post days of Christmas and New Year Celebration in three consecutive years (2019, 2020 and 2021)

experienced the highest concentration due to transportation, lesser restrictions of the lockdown, and the winter season usually has a higher concentration of NO_2. The post-festive days observed for all 3 years had the same level as observed during the festive period, and the only pollutants that recorded a low concentration level were SO_2 for the years 2019 and 2020. The air pollutant concentration for Punjab during pre-festive seasons recorded that $PM_{2.5}$ for 2019, 2020 and PM_{10} for 2020 and NO_2 for 2020 and 2021 have decreased during and post days of Christmas and new year. PM_{10}, NO_2, and SO_2 during the festive days of 2019 were very low compared to the pre-festival and post-festival days of that same year. While $PM_{2.5}$ and PM_{10} levels of 2021 experienced a high level of concentration. The festive post-period analyzed that the values of SO_2 for the years 2020 and 2021 have increased more than other pollutants. During the festival days in Madhya Pradesh, the PM_{10} decreased only for the year 2019.

The pre-festival period experienced higher values of PM_{10}, NO_2 in 2021, SO_2 in 2019, and during the post days of 2019, $PM_{2.5}$. For the year 2020, $PM_{2.5}$, PM_{10}, and SO_2 also recorded an increase in pollutant concentration. Rajasthan records higher concentrations for the post-festival days, i.e., $PM_{2.5}$ and PM_{10} for the three consecutive years and NO_2, SO_2 for 2020. The pollutants NO_2 for the year 2019 and SO_2 for 2021 have recorded the highest on pre-festive days, while NO_2 in 2021 and SO_2 in 2019 recorded the lowest. The year 2019, where there were no signs of COVID-19, concludes to have higher concentrations of the pollutants irrespective of pre-festive, during, and post-festive periods. As of 2020, when strict lockdown and curfews restrict travel and public gathering, most cities showed a drastic decrease in pollutant concentration. In 2021, as the lockdowns are not strict, being repeated as partial lockdown may have increased the pollutant concentrations. The public gathering is not restricted, and

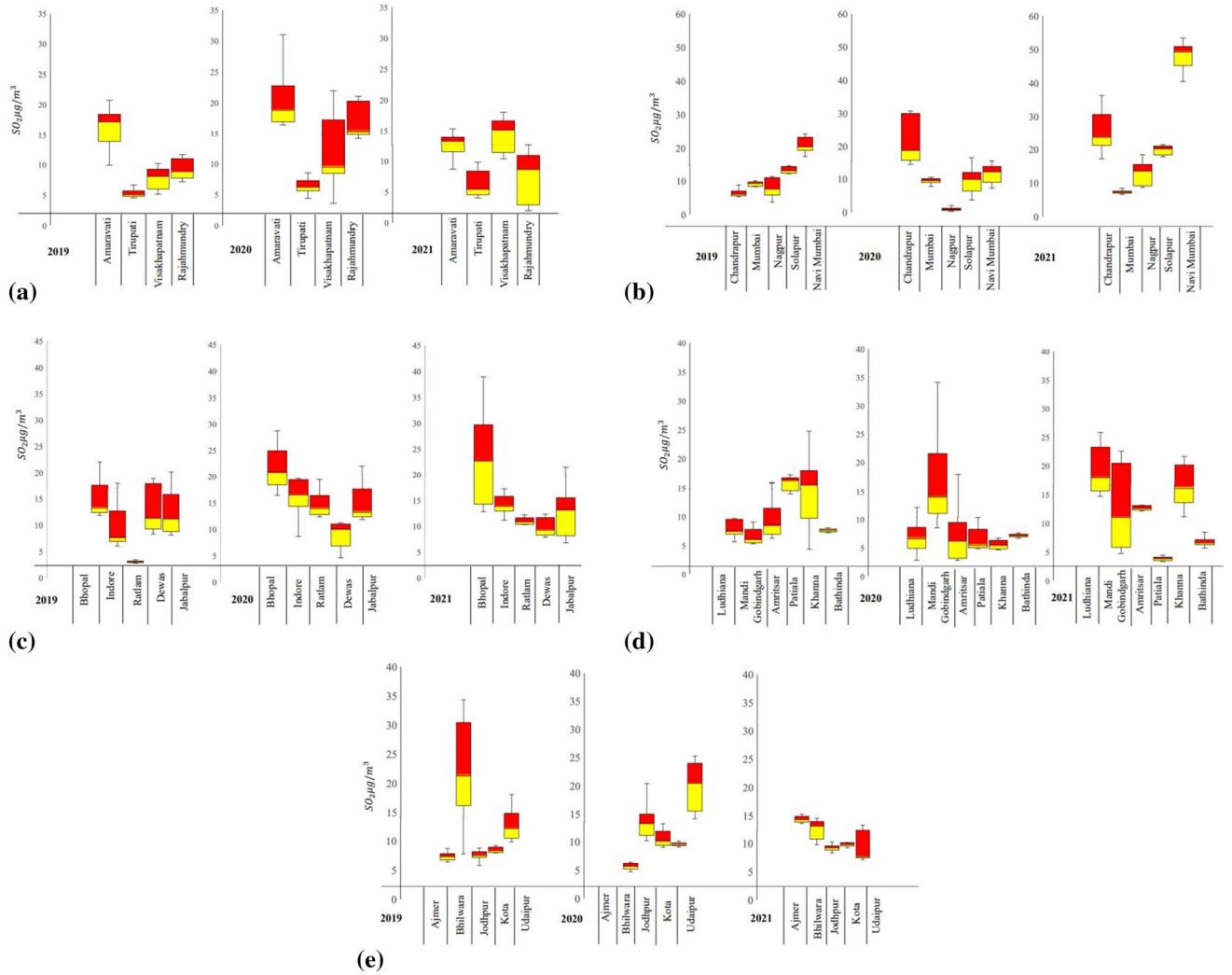

Fig. 3 The box plot showing the concentrations of SO_2 at various cities of Indian states like **a** Andhra Pradesh, **b** Maharashtra, **c** Madhya Pradesh, **d** Punjab, and **e** Rajasthan on pre, during, and post days of Christmas and New Year Celebration in three consecutive years (2019, 2020 and 2021)

transportation use even increased than before; the winter season also aids in more pollution due to the inversion height, pollutants cannot disperse.

3.3 Correlation analysis

Considering the timeframe for the pre, post, and during Christmas and a new year account, the pollutant data for all 3 years pollutants for the five states $PM_{2.5}$ and PM_{10} had a significant correlation ($p < 0.001$) (Fig. 6, 7, 8). Since they have relative compositions. $PM_{2.5}$ with SO_2 did not correlate; SO_2 for $PM_{2.5}$ and PM_{10} correlated ($p < 0.001$). NO_2 with SO_2 had a negative correlation ($p < 0.05$). SO_2 negatively correlates with the particulate matter levels ($p < 0.05$). From 1st December to 23rd December, the correlation between PM10 and SO2 stated a negative value ($p < 0.01$). NO_2 establishes a positive correlation with particulate matter. Similarly, SO_2 and NO_2 were nearly related to Madhya Pradesh. SO_2 and NO_2 positively correlated with particulate levels during the post-Christmas and new year time frame ($p < 0.001$). Before the festive time frame in Punjab, there was a positive correlation between SO_2, NO_2, $PM_{2.5}$, and PM_{10}. During the post-festive phase, NO_2 negatively correlated with the particulate levels and SO_2. Rajasthan had a positive correlation before the festive. NO_2 did not correlate with the other pollutants during the festive time frame. SO_2 exhibited a positive correlation with PM_{10} and $PM_{2.5}$. The correlation mostly lacked for the NO_2 and SO_2; these are dense gases that can cause severe lung diseases like bronchitis that can deteriorate the lungs' functionality. This can cause risk factors for COVID infected patients.

Fig. 6 Correlation matrices of four air pollutants for the selected states (**a**—Andhra Pradesh, **b**—Maharashtra, **c**—Madhya Pradesh, **d**—Punjab, **e**—Rajasthan), during pre-Christmas and New Year Celebration for the years 2019, 2020, and 2021

3.4 Role of meteorological parameters and interrelationship between pollutants

The metrological influence on the pollutants, like the wind speed, influences the pollutants' dispersal. If the wind is strong, the dispersion takes place faster and decreases the concentration levels of the pollutants. Relative humidity also influences the pollutants by the higher the relative humidity, the higher the air quality, which becomes a medium to carry bacterial and viral respiratory infections. Higher temperatures cause the air to be still and arrest the emitted pollutants. Lower temperatures cause the smoke or any pollution caused by any activity unable to disperse, even causing the gaseous emission to convert into particulate matter. Rainfall is a natural air cleanser, it increases the air quality and decreases the concentrations of the pollutants, as of winter, the following cities haven't experienced rain; hence it is recorded as 0 (Table 3). Tirupati had relatively less air temperature than the rest of the considered cities in Andhra Pradesh for 2019. In 2020 the cities recorded less temperature than 2021, during the festival time frame. Average humidity was higher for Tirupati and lesser for Rajahmundry. 2020 recorded an increase in relative humidity for the cities, and 2021 Vishakhapatnam had less relative humidity. Wind speed is seen maximum in Vishakhapatnam in 2019, a decrease in wind speed is observed in all four cities during the festive time in 2020. The wind speed is seen to increase again but is lesser than the values from 2019.

Ludhiana, Mandi Gobindgarh, and Patiala had a lesser average temperature than the rest of the cities, whereas, in 2020 and 2021, Ludhiana recorded more petite than the rest. Bathinda had lesser relative humidity for 2019 and higher for Mandi Gobindgarh. In 2020 Ludhiana had recorded less relative humidity than the rest of the cities. There is a decrease in the relative humidity for all the cities compared to 2019 and 2020. The average wind speed for cities in Punjab during the Christmas and new year records comparably same for 2019, and 2020 expect Amritsar recorded very low, but in 2021 there is a decrease in the

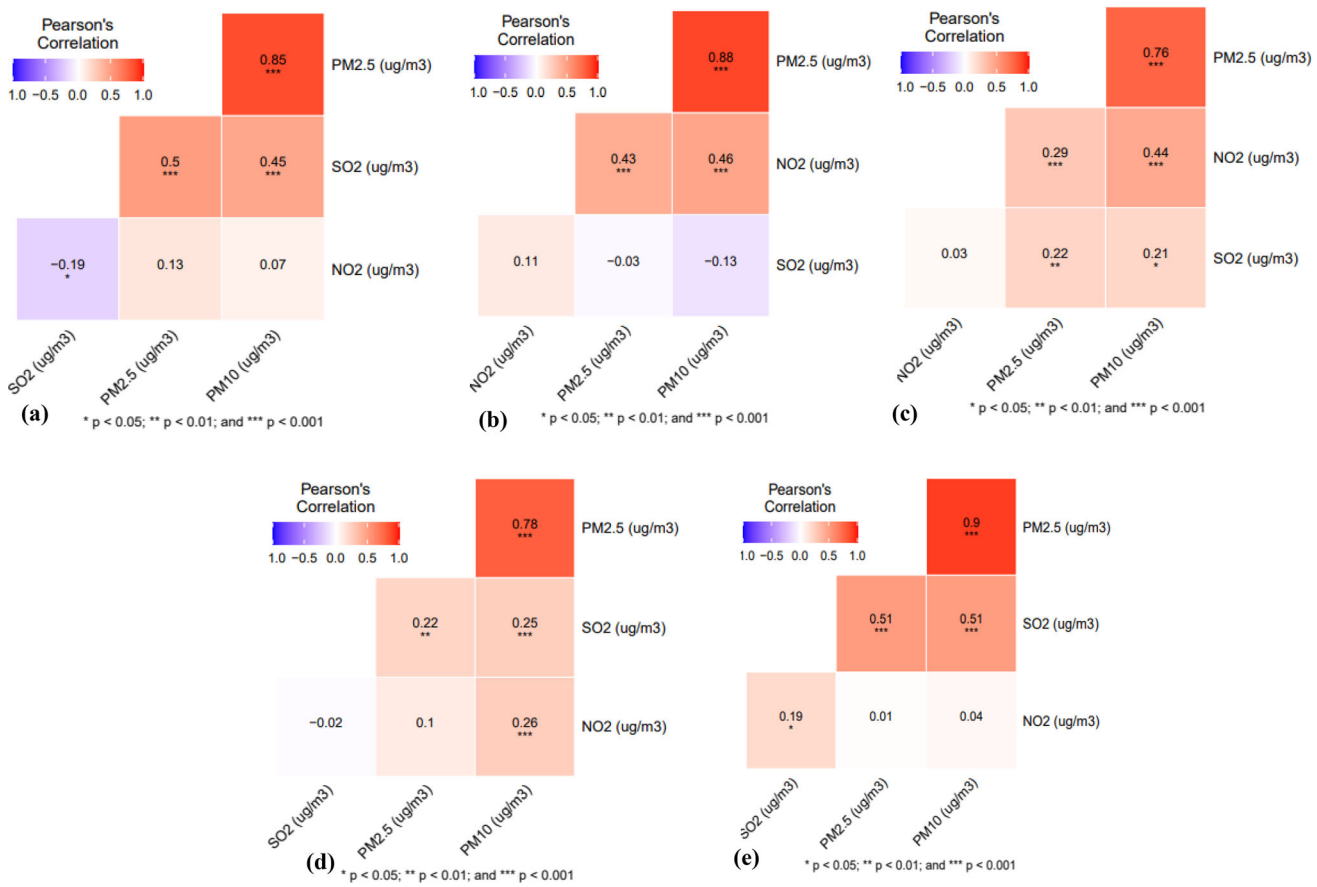

Fig. 7 Correlation matrices of four air pollutants for the selected states (**a**—Andhra Pradesh, **b**—Maharashtra, **c**—Madhya Pradesh, **d**—Punjab, **e**—Rajasthan), during Christmas and New Year Celebration for the years 2019, 2020, and 2021

wind speed when compared the previous years where Ludhiana and Amritsar seen with lesser values.

With the increased temperature of Nagpur and Chandrapur in 2020 and 2021, the other cities of Maharashtra have recorded a gradual decrease in the following years. The year 2019 and 2020 for Navi Mumbai and Mumbai have experienced the highest temperature levels than other cities. Maharashtra recorded a decrease in temperatures in 2020 and an increase in 2021. Wind speed remained more or less the same with minimal changes during the years. The relative humidity showed an interesting decrease pattern in all Rajasthan cities from 2020. It was noted that the increased humid levels recorded during the year 2021 were higher than the levels of the year 2019. Kota recorded the highest humid conditions in 2021, while other places were equal. The wind speed was more or less the same during all 3 years for December and January in all cities. In 2019 Rajasthan recorded lower temperatures while the years 2020 and 2021 witnessed an increase in temperatures. The rise was gradual and expected to increase the following year if this same condition occurs.

3.5 Spatial pattern of the parameters versus number of covid cases

The spatial mapping of air pollutants for each state is obtained from the data collected from each state's 3–5 important cities. Using Inverse distance weighted techniques in GIS Environment, the data is distributed among the boundaries of each state. The air pollutants level showed increasing during the festival time; this trend is uniformly seen in all the states taken in this study. The covid case data is also plotted to understand the movement followed when the lockdown is lifted during the festival. In 2020–2021, there was strict lockdown in India; hence the graph of that period follows the falling trend. However, there is no lockdown in the year 2021–2022, and people are allowed freely to move; this causes the number of cases to

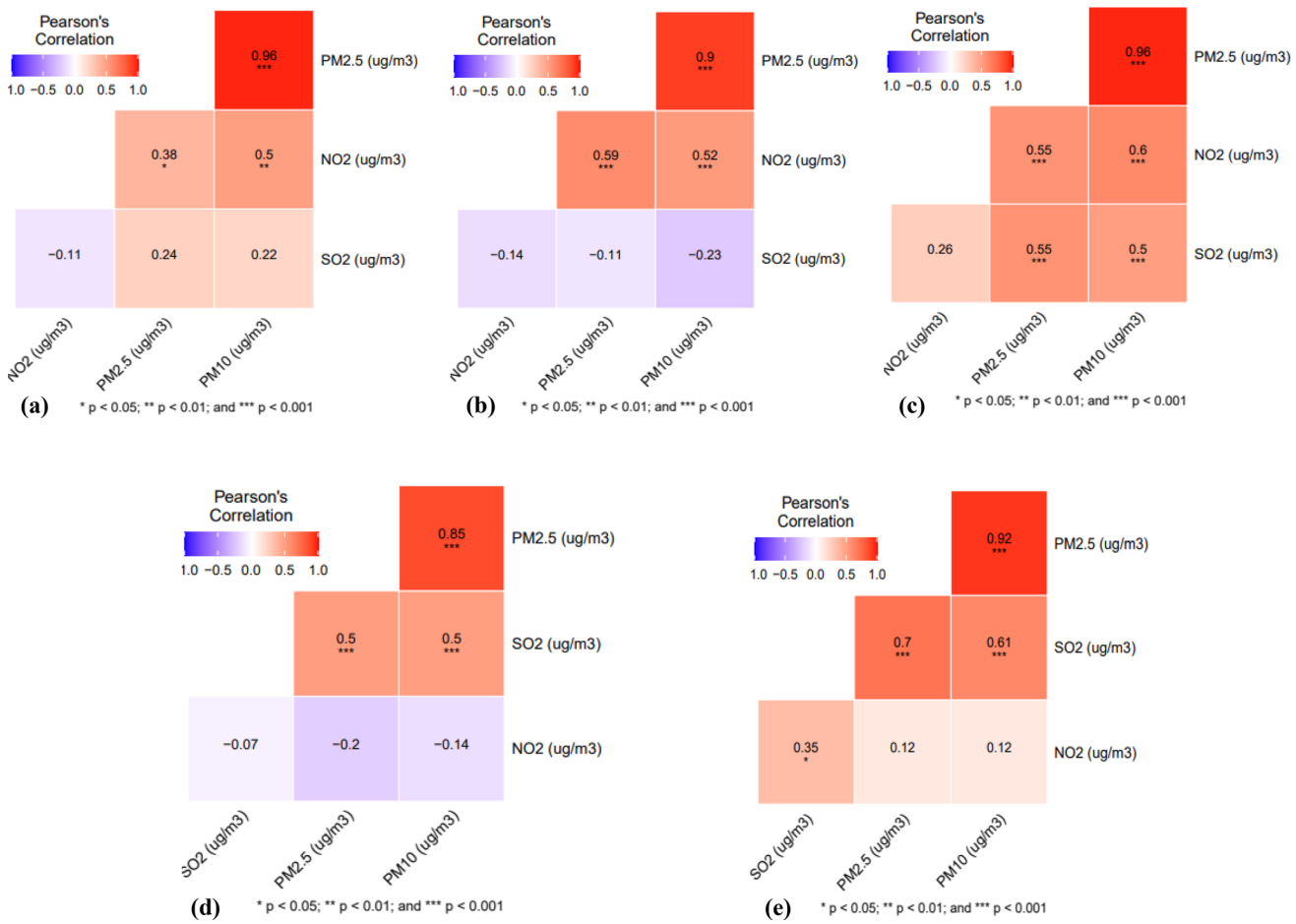

Fig. 8 Correlation matrices of four air pollutants for the selected states (**a**—Andhra Pradesh, **b**—Maharashtra, **c**—Madhya Pradesh, **d**—Punjab, **e**—Rajasthan),during post-Christmas and New Year Celebration for the years 2019, 2020, and 2021

increase rapidly, and this trend goes to its peak. This scenario is falling same for all the five cities.

The Andhra Pradesh parameter is mapped for the three consecutive years of 2019–2020, 2020–2021, and 2021–2022, as shown in Figs. 9–11. The air quality parameters reach the highest peak during the celebration in all 3 years, as clearly shown in Figs. 9–11. The $PM_{2.5}$ value of Andhra Pradesh in 2020–2021 is 111.71 μg m^{-3} (Fig. 10), whereas in 2021–2022 is 71.33 μg m^{-3} (Fig. 11). The number of COVID-19 cases in 2020–2021 is between 200 and 500, whereas in 2021–2022 is between 150 and 250, graph as shown in (Fig. 12). It shows the strong relation of air pollutants with covid cases. Another scenario from the graph obtained from the 2 years' data shows a rapid increase in cases during the festival when the lockdown is lifted. However, when there is a lockdown during the festival, it clearly states the falling of several covid cases. A similar scenario has been observed for the other states also.

Comparing state-wise, the highest $PM_{2.5}$ is observed for Rajasthan as 132.93 μg m^{-3} (Fig. 13); the Punjab state holds the lowest value of 95.037 μg m^{-3} (Fig. 14). The PM 10 parameter is highest for the state of Maharastra with the value of 213.004 μg m^{-3} (Fig. 15), and the lowest value is given for the Andhra Pradesh state. The SO_2 parameter is highest for Madhya Pradesh state with a value of 26.7392 μg m^{-3} Fig. 16 and the lowest for Rajasthan state with 17.906 μg m^{-3}. The NO_2 parameter is highest for the Maharashtra state and lowest for the Punjab State. Among all air pollutants, the NO_2 parameter is found to relate to the number of covid cases. If the NO_2 is high, then the number of COVID-19 cases in that state is highest. Also, the lowest holding NO_2 has fewer Covid cases of all states. This extensive study indicates that if NO_2 increases

Table 3 The statistical description of meteorological parameters during study periods

Cities	During Festival 24 Dec–Jan 01)	Temperature (°C)			Humidity (%)			Wind Speed (M/S)			Rainfall (inch)
		Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	
Andhra Pradesh											
Amaravati	2019–2020	25	23.7	23	78	74.9	72	5	3.3	1	0
	2020–2021	22	20.9	20	86	82.8	80	3	2.7	2	0
	2021–2022	22	21.8	21	88	86.6	85	4	3.0	2	0
Tirupathi	2019–2020	24	22.7	22	89	85.8	22	3	2.8	2	0
	2020–2021	22	20.7	20	91	87.8	86	4	3.0	2	0
	2021–2022	23	21.3	20	91	85.7	73	5	2.8	2	0
Vishakapatnam	2019–2020	24	22.6	21	85	76.1	71	7	4.7	2	0
	2020–2021	23	22.3	22	77	74.4	71	5	4.5	3	0
	2021–2022	24	23.4	23	85	76.0	67	6	3.4	1	0
Rajamahendravaram	2019–2020	25	22.8	22	81	74.1	68	6	3.8	2	0
	2020–2021	21	20.7	20	86	81.6	78	4	3.0	2	0
	2021–2022	23	22.1	22	89	85.0	78	5	2.8	1	0
Punjab											
Ludhiana	2019–2020	10	8.6	7	59	54.8	50	3	2.0	1	0
	2020–2021	13	10.6	8	67	54.3	50	3	2.5	1	0
	2021–2022	14	12.8	11	52	44.2	38	3	1.8	1	0
Mandigobindgarh	2019–2020	11	8.6	7	60	56.0	52	4	2.4	2	0
	2020–2021	13	11.0	9	61	49.4	44	4	2.9	1	0
	2021–2022	15	13.3	11	45	38.3	34	3	2.0	1	0
Amristar	2019–2020	10	9.0	8	59	51.1	45	2	1.6	1	0
	2020–2021	13	10.7	9	76	57.7	42	3	2.2	1	0
	2021–2022	15	13.3	11	52	40.9	30	3	1.7	1	0
Patiala	2019–2020	11	8.6	7	60	56.0	52	4	2.4	2	0
	2020–2021	13	11.0	9	61	49.4	44	4	2.9	1	0
	2021–2022	15	13.3	11	45	38.3	34	3	2.0	1	0
Khanna	2019–2020	11	9.3	7	56	52.4	48	3	2.3	2	0
	2020–2021	13	11.5	9	60	47.4	41	3	2.6	1	0
	2021–2022	15	13.5	12	41	38.4	34	3	2.1	2	0
Bathinda	2019–2020	11	9.0	7	56	49.0	44	2	2.0	1	0
	2020–2021	14	11.1	9	65	52.6	44	5	2.5	2	0
	2021–2022	15	13.6	12	62	40.6	27	3	2.0	1	0
Madhya Pradesh											
Bhopal	2019–2020	17	12.6	10	90	76.1	63	4	3.0	2	0
	2020–2021	17	15.2	13	66	54.5	47	4	3.1	2	0
	2021–2022	18	15.9	13	85	74.5	64	4	2.6	2	0
Indore	2019–2020	20	15.4	11	82	70.7	59	4	3.5	2	0
	2020–2021	19	17.1	16	60	50.8	39	4	3.3	3	0
	2021–2022	20	17.3	14	84	75.0	67	4	2.6	1	0
Ratlam	2019–2020	18	14.3	11	84	68.2	53	4	3.7	3	0
	2020–2021	19	16.8	14	62	47.3	31	5	3.8	3	0
	2021–2022	19	16.2	13	86	75.4	66	5	2.9	2	0
Dewas	2019–2020	19	15.1	10	84	73.5	61	4	3.0	2	0
	2020–2021	18	16.2	14	65	51.2	38	4	3.2	2	0
	2021–2022	19	16.3	13	85	76.3	71	4	2.6	2	0

Table 3 (continued)

Cities	During Festival 24 Dec–Jan 01)	Temperature (°C)			Humidity (%)			Wind Speed (M/S)			Rainfall (inch)
		Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	
Jabalpur	2019–2020	18	13.3	10	88	71.5	58	3	2.7	2	0
	2020–2021	17	15.7	15	64	58.3	51	3	2.5	2	0
	2021–2022	18	16.3	14	82	70.5	61	4	2.6	2	0
Maharashtra											
Chandrapur	2019–2020	22	18.4	14	83	71.4	58	4	2.6	1	0
	2020–2021	21	19.6	19	64	58.6	54	3	2.4	2	0
	2021–2022	22	20.3	18	88	76.0	63	4	2.3	1	0
Mumbai	2019–2020	25	22.6	19	84	78.3	72	4	2.7	2	0
	2020–2021	25	22.7	21	74	66.7	59	4	2.9	2	0
	2021–2022	23	21.6	20	78	73.1	67	5	2.9	2	0
Nagpur	2019–2020	21	16.4	12	85	72.0	58	4	2.9	1	0
	2020–2021	19	18.1	17	71	62.2	55	3	2.3	1	0
	2021–2022	21	19.3	17	86	73.0	60	4	2.1	1	0
Solapur	2019–2020	24	22.9	22	76	71.1	67	4	2.9	2	0
	2020–2021	22	20.7	20	74	69.8	67	3	2.9	2	0
	2021–2022	21	20.8	20	84	75.9	67	4	2.3	1	0
Navi Mumbai	2019–2020	25	22.6	19	84	78.3	72	4	2.7	2	0
	2020–2021	25	22.7	21	74	66.7	59	4	2.9	2	0
	2021–2022	23	21.6	20	78	73.1	67	5	2.9	2	0
Rajasthan											
Ajmer	2019–2020	14	10.9	9	68	54.6	41	5	3.2	2	0
	2020–2021	18	14.1	11	44	33.3	19	4	3.3	2	0
	2021–2022	16	14.4	12	84	72.4	54	3	2.4	2	0
Bhilwara	2019–2020	15	11.2	9	78	63.3	45	4	3.1	2	0
	2020–2021	18	14.6	11	52	34.5	16	4	3.0	2	0
	2021–2022	17	14.2	11	85	75.7	57	3	2.5	2	0
Jodhpur	2019–2020	16	12.4	11	61	43.8	31	4	3.4	3	0
	2020–2021	18	14.5	12	43	32.6	17	4	3.3	2	0
	2021–2022	18	15.3	13	77	62.9	44	3	2.6	2	0
Kota	2019–2020	15	11.7	10	88	70.8	51	4	2.6	2	0
	2020–2021	18	14.6	11	61	43.1	23	4	2.8	2	0
	2021–2022	18	14.2	10	94	80.7	69	3	2.3	2	0
Udaipur	2019–2020	17	12.7	10	79	63.7	49	5	3.6	3	0
	2020–2021	18	14.9	11	62	43.2	27	4	3.1	2	0
	2021–2022	18	15.0	12	90	74.1	57	4	2.7	2	0

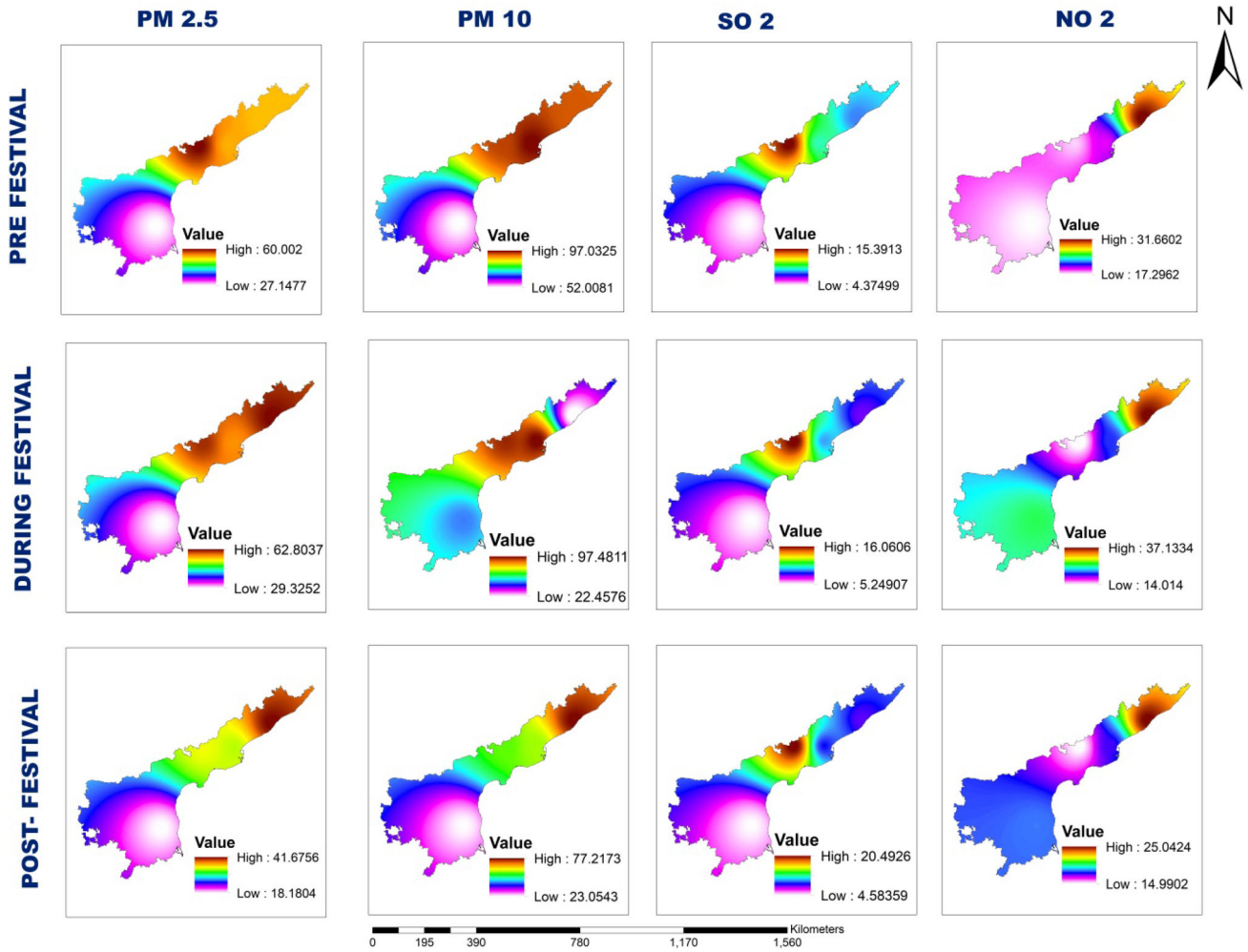

Fig. 9 Pollution data of Andhra Pradesh during the festival of Christmas and New Year for the year of 2019–2020

the vehicle movement, which directly impacts the increase of covid cases.

4 Conclusion

This current study analyzed air pollutant concentrations in five major states of India, namely Andhra Pradesh, Maharashtra, Madhya Pradesh, Punjab, and Rajasthan, during December and January. The study was carried out to examine the difference in the air pollutant levels during Christmas and new year days. These year-end days always experience a high level of mobility and celebration, which will even be aggravated with winter weather conditions. The statistical analyses of the data help one understand the changes in the air pollutant concentration between 2019, 2020, the pandemic, and 2021. The citizens were forced to be at their homes to prevent the COVID-19 wave from spreading due to restrictions embedded by Indian Govt laws. The pre-festive days, during Christmas and new year, post-festive days witnessed different variations in all these states. When the pandemic wave became weak, the awareness towards the people was ineffective, which paved the way for the activities that were believed to be the stimulation for the spread of the covid virus-like public gatherings, traveling, and not following the rules given by the Government. The negligence and failure to realize the catastrophic adamance to abide by the rules resulted in the increase of COVID-19 cases and the sudden increase of pollution in the year 2021. When pollutant concentrations are more significant than the permissible limit, the COVID-19 virus spreads rapidly; several types of research have

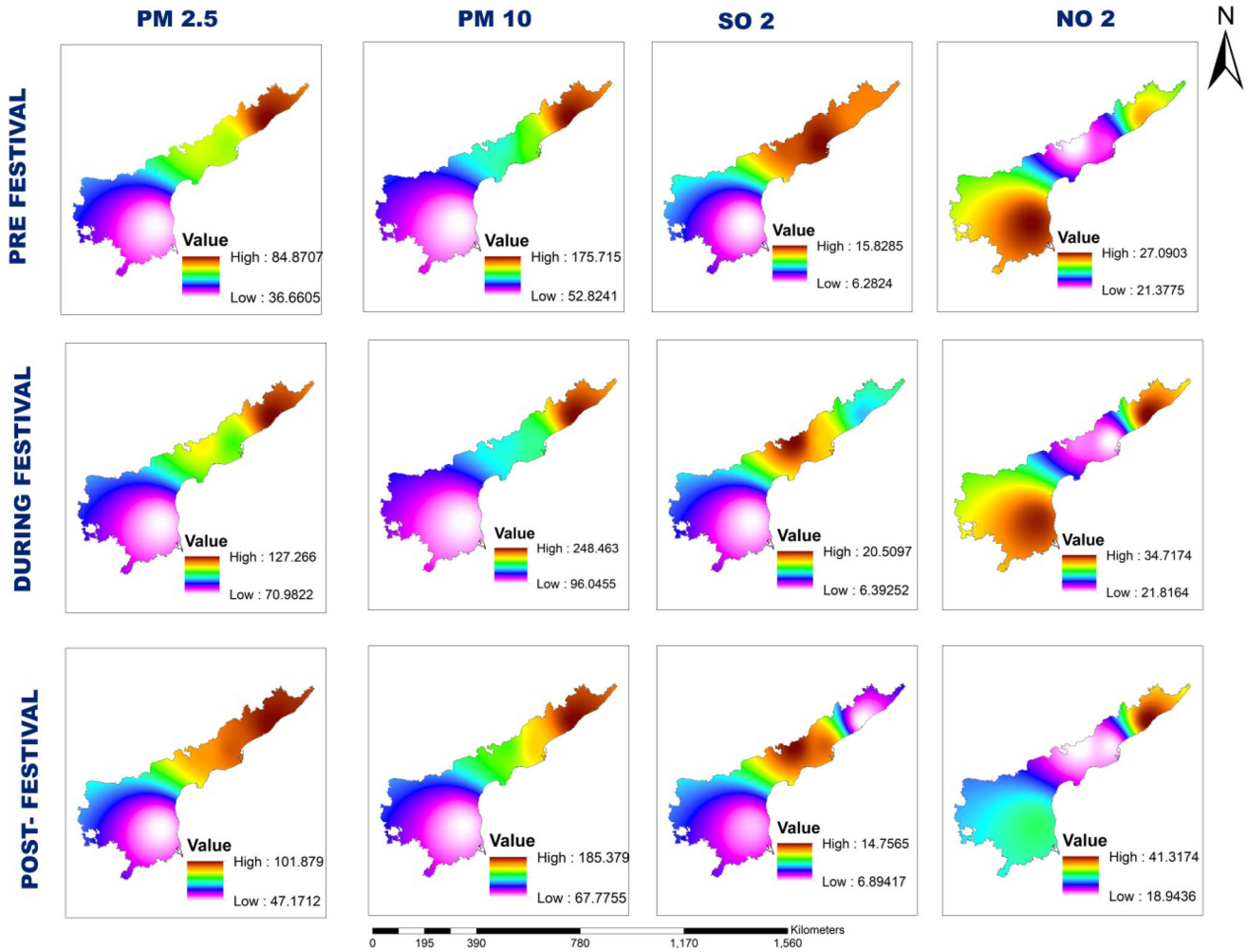

Fig. 10 Pollution data of Andhra Pradesh during the festival of Christmas and New Year for the year of 2020–2021

been evident to prove that particulate matters facilitate COVID-19. The pollutants have increased due to transportation as Lockdown had been initiated only for some months in 2021, which caused the particulate matters to be one of the mediums to facilitate COVID-19 probably. The presence of the pollutants causes not only COVID-19 but also lung, respiratory and cardiovascular diseases. These can prolong the recovering rate of the suspected patients,

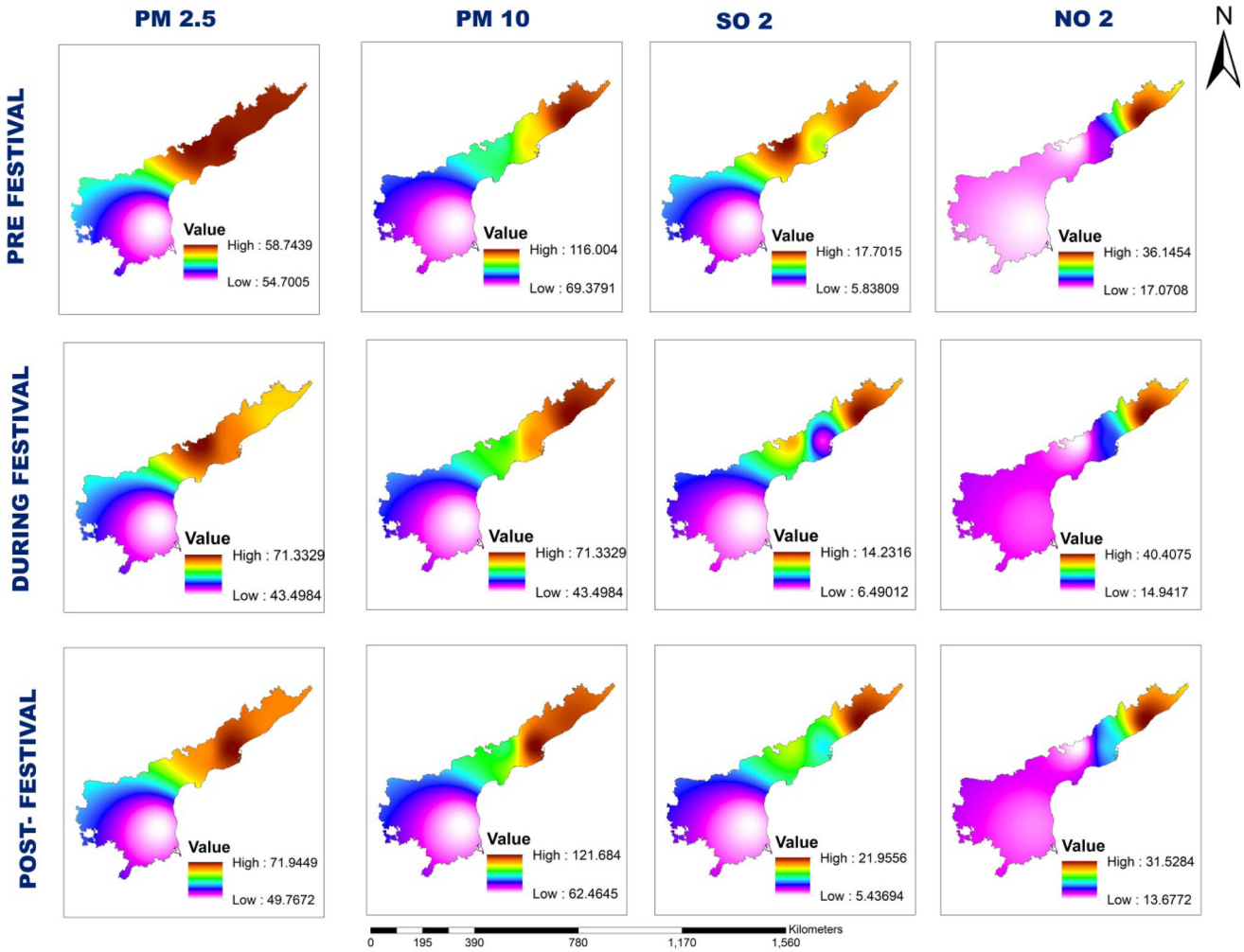

Fig. 11 Pollution data of Andhra Pradesh during the festival of Christmas and New Year for the year of 2021– 2022

even a normal human being. This study tries to expose the $PM_{2.5}$, PM_{10}, NO_2, SO_2 concentrations during the Christmas and new year days in the selected five states. This work initially shows that due to the strict Lockdown, hygiene methods, and serval death due to the COVID-19 throughout the country, there was less involvement during the year-end days of December 2020. Even though admits of increase in COVID-19 cases in 2021, partial Lockdown, and lifting of specific rules, the country may have faced a massive rise in air pollution levels than 2019 in many major cities of selected states like Rajasthan, Madhya Pradesh, and Maharashtra. The return of normal life, even

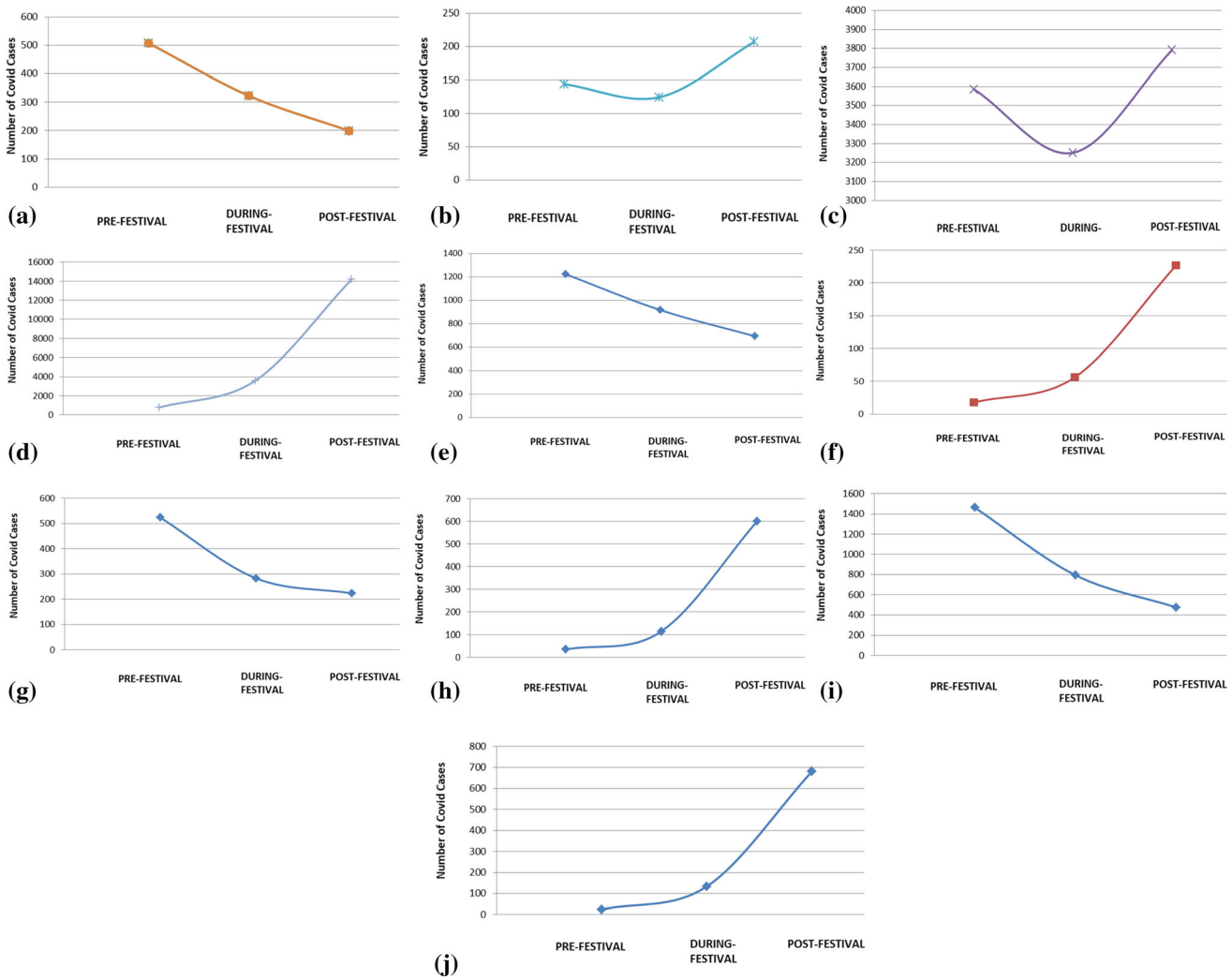

Fig. 12 Number of COVID-19 cases for selected states during the festival of Christmas and New Year Celebration; **a** Andhra Pradesh (2020–21), **b** Andhra Pradesh (2021–22), **c** Maharashtra (2020–21), **d** Maharashtra (2021–22), **e** Madhya Pradesh (2020–21), **f** Madhya Pradesh (2021–22), **g** Punjab (2020–21), **h** Punjab (2021–22), **i** Rajasthan (2020–21), and Rajasthan (2021–22)

though strict laws have been enforced, the return of normal life, the adaptation, and carelessness towards the endanger of COVID-19 have become a part of life. This situation out forces the state of social distancing and movement of people from place to place.

Maharashtra was the only state to see a decrease in pollutant concentration after the festive days and showed a high rise in pollutant concentration during the festival days as the citizens have been using the transport system during these festival days. While these other states, excluding Maharashtra, showed the movement of people on pre-

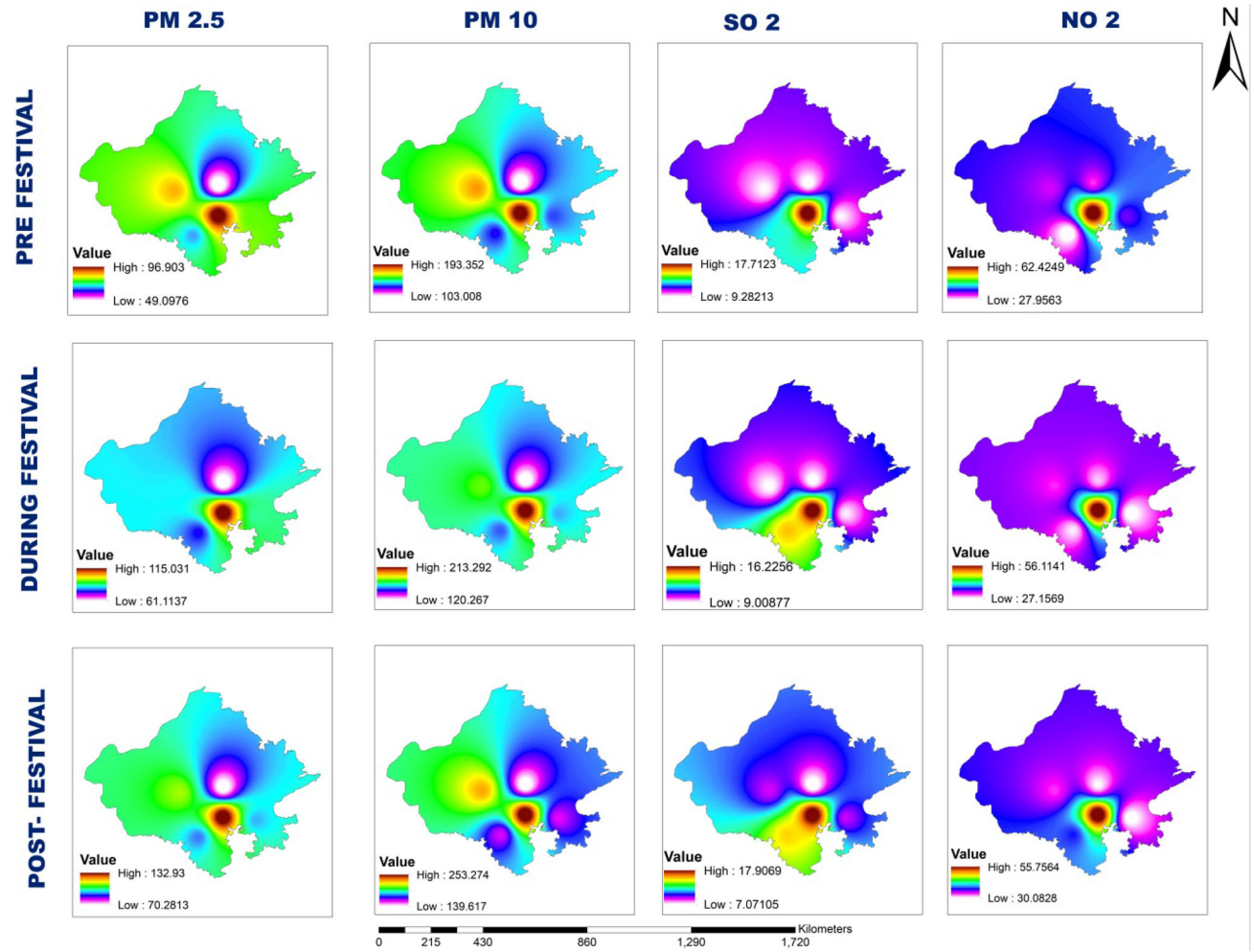

Fig. 13 Average Pollution data for the year of 2019–20, 2020–21 and 2021–22 of Rajasthan during the festival of Christmas and New Year

festive days, which stimulated the increase of pollution level. Lockdown is also considered one of the reasons for the decrease in pollution. Maharashtra experienced a higher COVID-19 case spread than other states. This scenario is another reason for the people to stop gathering for celebrations at this crucial time which would cause a low pollution level. Though wind speed remained consistent in all places, temperature and humidity played a major role. Punjab and Andhra Pradesh experienced heatwaves that paved the way for the low spread of the virus, but some cities of these states had witnessed a mere hike in COVID-19 new cases, neglecting the facts of social distancing.

On the other hand, the other three states experienced cold temperatures, which made air pollutants get damped in one place, becoming a probable carrier for COVID-19. Based on the following study, it is noted that in 2019

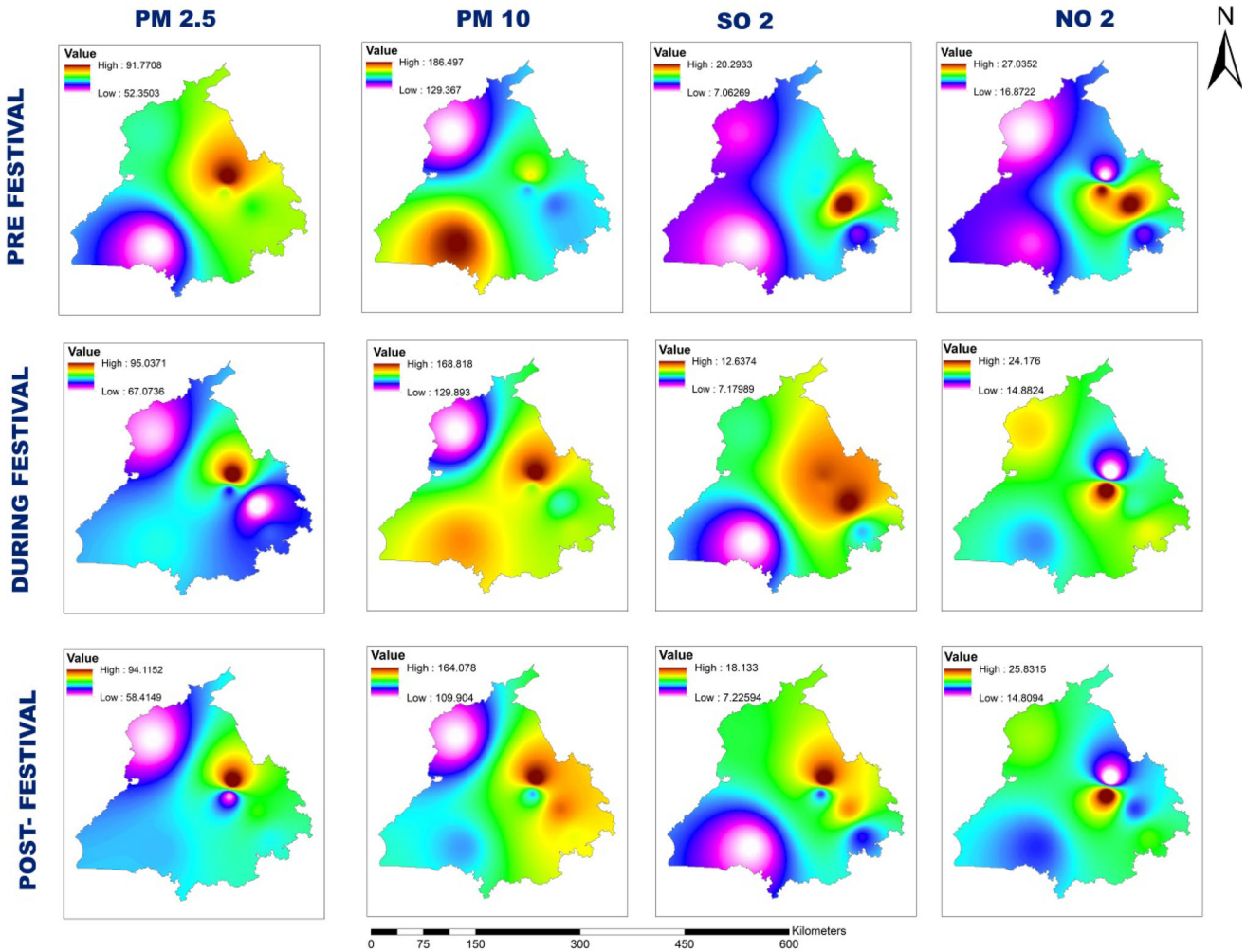

Fig. 14 Average Pollution data for the year of 2019–20, 2020–21 and 2021–22 of Punjab during the festival of Christmas and New Year

before the reach of COVID-19 affected people had usually been polluting the atmosphere with transportation, use of crackers constructions chemical discharges from industries, etc. Due to the lockdowns, the pollutant concentrations decreased, but when this became a usual scenario, people adapted, and they are overexploiting than usual years in 2021 as having restrictions than the year 2020. The year 2021 recorded a higher air pollution concentration than the previous years for some states. Overall, the comparison of the festival days study reveals that the population had been active only on pre-festive and post-festive days while half the populations maintained their idleness during festival days. This 2021 pattern continues. It is feared that the COVID-19 will be rapidly spreading with new variants in

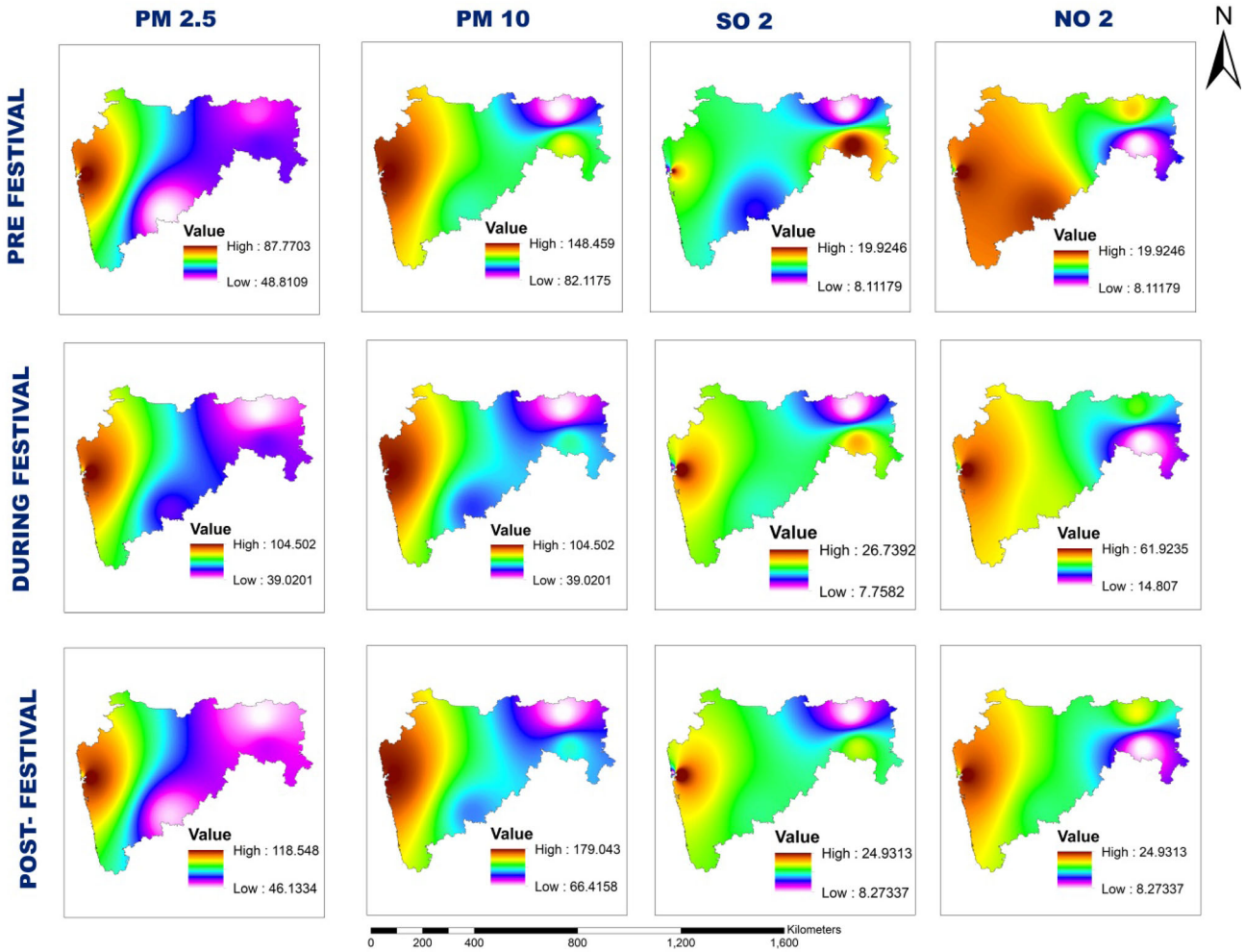

Fig. 15 Average Pollution data for the year of 2019–20, 2020–21 and 2021–22 of Maharashtra during the festival of Christmas and New Year

the mid-January weeks and will fade in the later months of June and August. The sudden vacations and work from home from job places have motivated a large allocation of people to their home towns and gatherings, parties, celebrations, and religious sermons, resulting in the rise of COVID-19. Indian Govt. has to make proper decisions and regulations during these days. As it has been understood, full enforcement of Lockdown will not be achievable; instead, partial lockdowns or Lockdown on pre-festival days will surely contain the COVID-19 spread. Proper awareness has to be given to all the citizens and immigrants irrespective of political belief to disclose the situation and to be taken seriously; these pre-festive days, festive days, and post-festive days play a significant role in increasing

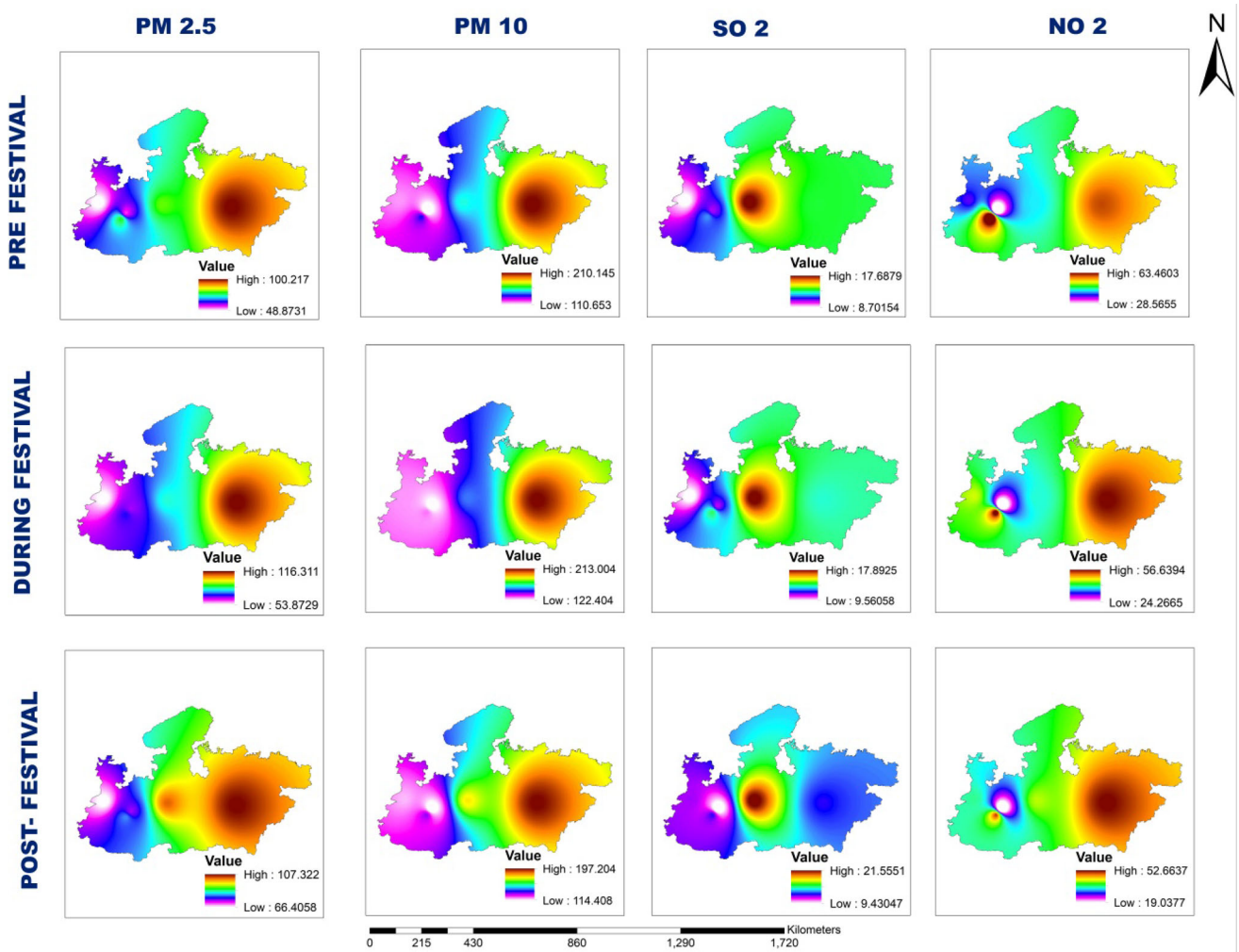

Fig. 16 Average Pollution data for the year of 2019–20, 2020–21 and 2021–22 of Madhya Pradesh during the festival of Christmas and New Year

air pollutant concentrations, which doubles the spread of COVID-19 over other months. Proposed highlights will help in developing a sustainable environment for now and in the future.

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Declarations

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

References

Ambade B (2018) The air pollution during Diwali festival by the burning of fireworks in Jamshedpur city, India. Urb Clim 26:149–160. https://doi.org/10.1016/j.uclim.2018.08.009

Anand V, Korhale N, Rathod A, Beig G (2019) On processes controlling fine particulate matters in four Indian megacities. Environ Pollut 254:113026. https://doi.org/10.1016/j.envpol.2019.113026

Arora AS, Rajput H, Changotra R (2021) Current perspective of COVID-19 spread across South Korea: exploratory data analysis and containment of the pandemic. Environ Dev Sustain 23:6553–6563

Attri AK, Kumar U, Jain VK (2001) Formation of ozone by fireworks. Nature 411(6841):1015. https://doi.org/10.1038/35082634

Bisht L, Gupta V, Singh A, Gautam AS, Gautam S (2022) Heavy metal concentration and its distribution analysis in urban road dust: a case study from most populated city of Indian state of Uttarakhand. Spat Spat Tempor Epidemiol 40:100470

Camilleri R, Vella AJ (2010) Effect of fireworks on ambient air quality in Malta. Atmos Environ 44(35):4521–4527. https://doi.org/10.1016/j.atmosenv.2010.07.057

Changotra R et al (2020) Largest democracy in the world crippled by COVID-19: current perspective and experience from India. Environ Dev Sustain. https://doi.org/10.1007/s10668−020−00963-z

Chatterjee A, Sarkar C, Adak A, Mukherjee U, Ghosh SK, Raha S (2013) Ambient air quality during Diwali festival over Kolkata-a

mega-city in India. Aerosol Air Qual Res 13(3):1133–1144. https://doi.org/10.4209/aaqr.2012.03.0062
Chattopadhyay A, Shaw S (2021) Association between air pollution and COVID-19 pandemic: an investigation in Mumbai India. GeoHealth. https://doi.org/10.1029/2021GH000383.e2021GH000383
Chelani A, Gautam S (2021) Lockdown during COVID-19 pandemic: a case study from Indian cities shows insignificant effects on urban air quality. Geosci Front. https://doi.org/10.1016/j.gsf.2021.101284
Chelani A, Gautam S (2022) The influence of meteorological variables and lockdowns on COVID-19 cases in urban agglomerations of Indian cities. Stoch Env Res Risk Assess. https://doi.org/10.1007/s00477−021−02160−4
Chhabra A, Turakhia T, Sharma S, Saha S, Iyer R, Chauhan P (2020) Environmental impacts of fireworks on aerosol characteristics and radiative properties over a mega city India. City Environ Interact 7:100049. https://doi.org/10.1016/j.cacint.2020.100049
Coccia M (2021) How do low wind speeds and high levels of air pollution support the spread of COVID-19? Atmos Pollut Res 12(1):437–445. https://doi.org/10.1016/j.apr.2020.10.002
Gangwar HS, Ray PC (2021) Geographic information system-based analysis of COVID-19 cases in India during pre-lockdown, lockdown, and unlock phases. Int J Infect Dis 105:424–435. https://doi.org/10.1016/j.ijid.2021.02.070
Garaga R, Kota SH (2018) Characterization of PM10 and impact on human health during the annual festival of lights (Diwali). J Health Pollut 8(20):181206. https://doi.org/10.5696/2156−9614−8.20.181206
Garaga R, Kota SH (2021) Characterization of PM 10 and its impact on human health during annual festival of lights (Diwali) in Northeast India. Urban air quality monitoring modelling and human exposure assessment. Springer, Singapore, pp 305–323
Gautam S (2020a) The influence of COVID–19 on air quality in India: a boon or inutile. Bull Environ Contam Toxicol 104(6):724–726
Gautam S (2020b) COVID–19: air pollution remains low as people stay at home. Air Qual Atmos Health. https://doi.org/10.1007/s11869−020−00842−8
Gautam S, Brema J (2020) Spatio-temporal variation in the concentration of atmospheric particulate matter: a study in fourth largest urban agglomeration in India. Environ Technol Innov 17:100546. https://doi.org/10.1016/j.eti.2019.100546
Gautam S, Setu S, Khan MGQ, Khan B (2022) Analysis of the health, economic and environmental impacts of COVID-19: the Bangladesh perspective. Geosys Geoenviron. https://doi.org/10.1016/j.geogeo.2021.100011
Gowda G, Gurupadaswamy SM, Athani SB (2020) A study on respiratory morbidities among school children post Diwali in Bangalore city. Indian J Allergy Asthma Immunol 34(2):107–111. https://doi.org/10.4103/ijaai.ijaai_21_20
Greenberg N, Carel RS, Derazne E, Tiktinsky A, Tzur D, Portnov BA (2017) Modeling long-term effects attributed to nitrogen dioxide (NO2) and sulfur dioxide (SO2) exposure on asthma morbidity in a nationwide cohort in Israel. J Toxicol Environ Health A 80(6):326–337. https://doi.org/10.1080/15287394.2017.1313800
Gupta A, Bherwani H, Gautam S, Anjum S, Musugu K, Kumar N, Anshul A, Kumar R (2020) Air pollution aggravating COVID-19 lethality? Exploration in Asian cities using statistical models. Environ Dev Sustain. https://doi.org/10.1007/s10668-020-00878-9
Humbal C, Gautam S, Trivedi U (2018) A review on recent progress in observations, and health effects of Bioaerosols. Environ Int 118:189–193
Humbal C, Gautam S et al (2019) Evaluating the colonization and distribution of fungal and bacterial bioaerosol in Rajkot, western India using multi-proxy approach. Air Qual Atmos Health 12(6):693–704
Klima V, Chady siene R, Ivanec-Goranina R, Jasaitis D, Vasiliauskiene V (2020) Assessment of air pollution with polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofuranes (PCDFs) in Lithuania. Atmosphere 11(7):759. https://doi.org/10.3390/atmos11070759
Kulshrestha UC, Rao NT, Azhaguvel S, Kulshrestha MJ (2004) Emissions and accumulation of metals in the atmosphere due to crackers and sparkles during Diwali festival in India. Atmos Environ 38(27):4421–4425. https://doi.org/10.1016/j.atmosenv.2004.05.044
Kumari P, Singh HP, Singh S (2021) SEIAQRDT model for the spread of novel coronavirus (COVID-19): a case study in India. Appl Intell 51(5):2818–2837. https://doi.org/10.1007/s10489−020−01929−4
Liu J, Chen Y, Chao S, Cao H, Zhang A (2019) Levels and health risks of PM2.5-bound toxic metals from firework/firecracker burning during festival periods in response to management strategies. Ecotoxicol Environ Saf 171:406–413. https://doi.org/10.1016/j.ecoenv.2018.12.104
Mallapaty S (2021) India's massive COVID surge puzzles scientists. Nature 592(7856):667–668
Naqvi HR, Datta M, Mutreja G, Siddiqui MA, Naqvi DF, Naqvi AR (2021) Improved air quality and associated mortalities in India under COVID-19 lockdown. Environ Pollut 268:115691. https://doi.org/10.1016/j.envpol.2020.115691
Nori P, Cowman K, Chen V, Bartash R, Szymczak W, Madaline T, Guo Y (2021) Bacterial and fungal coinfections in COVID-19 patients hospitalized during the New York city pandemic surge. Infect Control Hosp Epidemiol 42(1):84–88. https://doi.org/10.1017/ice.2020.368
Ogen Y (2020) Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality. Sci Total Environ 726:138605. https://doi.org/10.1016/j.scitotenv.2020.138605
Rahimi F, Abadi ATB (2020) Practical strategies against the novel coronavirus and COVID-19—the imminent global threat. Arch Med Res 51(3):280–281. https://doi.org/10.1016/j.arcmed.2020.03.005
Rajput H et al (2020) A shock like no other: coronavirus rattles commodity markets. Environ Dev Sustain. https://doi.org/10.1007/s10668−020−00934
Ranjbari M, Esfandabadi ZS et al (2021) Three pillars of sustainability in the wake of COVID-19: A systematic review and future research agenda for sustainable development. J Clean Prod 297:126660
Ranjbari M, Esfandabadi ZS, Gautam S, Ferraris A, Scagnelli SD (2022) Waste management beyond the COVID-19 pandemic: Bibliometric and text mining analyses. Gondwana Res. https://doi.org/10.1016/j.gr.2021.12.015
Ravina M, Esfandabadi ZS, Panepinto D, Zanetti M (2021) Traffic-induced atmospheric pollution during the COVID-19 lockdown: Dispersion modeling based on traffic flow monitoring in Turin Italy. J Clean Prod 317:128425
Sarkar R, Mitra S, Chandra P, Saha P, Banerjee A, Dutta S, Chawla-Sarkar M (2021) Comprehensive analysis of genomic diversity of SARS-CoV−2 in different geographic regions of India: an endeavour to classify Indian SARS-CoV−2 strains on the basis of co-existing mutations. Adv Virol 166(3):801–812. https://doi.org/10.1007/s00705−020−04911−0
Sathe Y, Gupta P, Bawase M, Lamsal L, Patadia F, Thipse S (2021) Surface and satellite observations of air pollution in India during COVID-19 lockdown: implication to air quality. Sustain Cities Soc 66:102688. https://doi.org/10.1016/j.scs.2020.102688

Sharma A, Bedi M, Patel P, Arora AS (2022) Black fungus outbreak in India—a direct consequence of COVID-19 surge: a myth or reality. Gondwana Res. https://doi.org/10.1016/j.gr.2021.12.016

Soni P (2021) Effects of COVID-19 lockdown phases in India: an atmospheric perspective. Environ Dev Sustain 23:12044–12055. https://doi.org/10.1007/s10668−020−01156−4

Travaglio M, Yu Y, Popovic R, Selley L, Leal NS, Martins LM (2021) Links between air pollution and COVID-19 in England. Environ Pollut 268:115859. https://doi.org/10.1016/j.envpol.2020.115859

Wang Z, Lin L, Guo Y, Xiong H, Tang K (2021) The uncounted casualties of a hidden COVID-19 epidemic in China: cross-sectional study on deaths related to overwork. J Med Internet Res 23(4):e23311. https://doi.org/10.2196/23311

Zoran MA, Savastru RS, Savastru DM, Tautan MN (2020) Assessing the relationship between ground levels of ozone (O3) and nitrogen dioxide (NO2) with coronavirus (COVID-19) in Milan Italy. Sci Total Environ 740:140005. https://doi.org/10.1016/j.scitotenv.2020.140005