



# Epigrammatic study on the effect of lockdown amid Covid-19 pandemic on air quality of most polluted cities of Rajasthan (India)

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## Abstract

Covid-19 pandemic has adversely affected all the aspects of life in adverse manner; however, a significant improvement has been observed in the air quality, due to restricted human activities amidst lockdown. Present study reports a comparison of air quality between the lockdown duration and before the lockdown duration in seven selected cities (Ajmer, Alwar, Bhiwadi, Jaipur, Jodhpur, Kota, and Udaipur) of Rajasthan (India). The period of analysis is 10 March 2020 to 20 March 2020 (before lockdown period) versus 25 March to 17 May 2020 (during lockdown period divided into three phases). In order to understand the variations in the level of pollutant accumulation amid the lockdown period, a trend analysis is performed for 24 h daily average data for five pollutants (PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub>, SO<sub>2</sub>, and ozone).

**Keywords** Covid-19 · Air quality · NO<sub>2</sub> · Air pollutant · Particulate matter · Ozone

## Introduction

At the end of the year 2019, China's health authority ominously reported to the World Health Organization (WHO) about a severe type of pneumonia in Wuhan city of Hubei Province in central China (Lu et al. 2020). The report addressed the severe acute respiratory syndrome corona virus (SARS-CoV-2), now popularly known as Covid-19. It was declared as a pandemic on March 11, 2020, by WHO (Gorbalenya et al. 2020); it has caused over 4.8 million global infections and more than 3.2 lakhs confirmed deaths in 216 countries, as of this writing (21 May 2020) (WHO 2020). In India, over one lakh cases have been confirmed with a death record of over 3700, until 21 May 2020 (GOI (Government of India) 2020).

Considering the population in India, the conditions are still not as frightening as in other countries of the world. This can be attributed to the early preventive measures taken by the government of India. In order to combat the pandemic and

restrict the further spread of the virus from one source to another, multiple interventions, including lock down, have been implemented. The schedule of the Covid-19 pandemic lockdown in India is given in Table 1.

The lockdown includes ban on travel on all modes of transports (surface, air, and water) and closures of factories, causing cessation of business including tourism, various industries, local markets, construction, food business, and mining. However, there was a time liberty for essential services like medicines, groceries, fruits, and vegetables. The immediate lateral consequence is observed as dip in the economy, globally and nationwide, that may take years to return at par with the previous conditions. The lockdown has benefited the environment in terms of improvement in air quality and water quality, and decline in noise pollution level (Mandal and Pal 2020; Masum and Pal 2020; Bherwani et al. 2020). Worldwide, many researchers have reported a waning in the air pollution due to restricted social and economical activities amidst lockdown (Bao and Zhang 2020; Jain and Sharma 2020).

As per data of World Air Quality Report (2018–2019) and other sources (2020), more than 20 Indian cities are in the 30 most polluted cities in the world (WAQR, World air quality report 2019; WAQR, World air quality report 2018; CNN Health 25th 2020). In the year 2018, four cities of Rajasthan were in top 100 most polluted cities in world with Bhiwadi city at the fifth position (WAQR, World air quality report 2018). According to a report (2018), Rajasthan has the highest

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**Table 1** Schedule of Covid-19 pandemic lockdown in India

Phase	Start of the lockdown	End of the lockdown	Total days
Phase - 1	25 March 2020	14 April 2020	21
Phase - 2	15 April 2020	3 May 2020	19
Phase - 3	4 May 2020	17 May 2020	14
Phase - 4	18 May 2020	Ongoing (scheduled to end on 31 May)	-

death rate per lakh due to air pollution, i.e., because of exposures to ambient air pollutants over a prolonged period of time (TOI (Times of India) 2018).

Considering the previous severe pollution situation in Rajasthan, we have studied the current air quality in seven cities of Rajasthan: Ajmer, Alwar, Bhiwadi, Jaipur, Jodhpur, Kota, and Udaipur.

### Types of air pollutants and their sources (Aranha 1994)

On the basis of origin, air pollutants can be categorized as primary or secondary. Primary air pollutants are directly emitted into the air from their source. For example, oxides of sulfur, oxides of nitrogen, and oxides of carbon are primary air pollutants.

Sulfur dioxide (SO<sub>2</sub>) is formed due to burning of non-conventional fuels, agriculture wastes or residues, or from industries. It is considered to be toxic after a certain concentration. It is also responsible for acid rain formation. Nitrogen oxides (NO<sub>x</sub>), like nitrogen dioxide (NO<sub>2</sub>), are formed during combustion of fossil fuels, biomass, etc. It may also react with carbon monoxide in the atmosphere to form ozone. It is also responsible for acid rain. Carbon monoxide (CO) is formed due to incomplete combustion of carbon in fuels like motor and industry biomass.

Secondary air pollutants are formed due to the reaction of primary air pollutants in the atmosphere. For example, ozone (O<sub>3</sub>) is formed by free radical reactions of nitrogen oxides. Smog is formed from smoke and fog. The particulate matter (PM) (aerosols) are the solid and liquid particles suspended in the air, viz., organic compounds, metals, acids, soil, and dust. Thus, they include both organic and inorganic matter. These coarse particles are formed by mechanical break up of large solid particles obtained from non-combustible materials produced during combustion of fossil fuels, agricultural processes, mining of ores, construction of roads, etc.

The different kind of air pollutants and their sources are summarized in Table 2.

### Area of study

Rajasthan, the largest state of the India, is located at the north-western part of the country. The state lies between N-latitude

23° 31' to 30° 12' and E-longitude 69° 3' to 78° (Fig. 1) with an area of about 3.4 km<sup>2</sup> (Maps of India 2011). Geomorphologically, the state can be divided into four units, viz., Eastern plain areas, Aravali hill ranges and adjacent areas, Western sandy plains and sand dunes, and low lying Vindhayan hill. The State suffers from impulses of monsoon, showing rainfall as low as 170 mm in the western part of the state and as high as 819 mm in the eastern part of the state (Maanju and Saha 2013).

At the time of establishment of Rajasthan, the economy of the State was predominantly an agrarian economy. The state has an agricultural economy with nine agro-climatic zones and various types of soil that help during the cultivation of crops. With the advent of industrialization, it started playing an important role in providing substantial employment and generating the income and boosting the standard of living and overall welfare of people. Majorly, industries started flourishing in Kota, Jaipur, Udaipur, Bhilwara, Bhiwadi, and few other Industrial Estates of Rajasthan. The key industries of Rajasthan are cement, tourism, ceramic, chemicals, textiles, steel, handicrafts, IT and ITeS, and marble (Maps of India 2011; Report 2018). Researchers have reported that in Rajasthan, the industrial activities, mining, and automobiles are responsible for air pollution (Kumar and Sharma 2016; Chauhan 2010). In India, Rajasthan is one of the largest mineral-producing states, with availability of more than 80 kinds of minerals out of which 57 minerals are produced commercially. The tourist attractions of Rajasthan (historic monuments, wildlife sanctuaries, deserts, etc.) offer an attractive investment opportunity to developers and investors. Also, the state is the leading producer of cement grade limestone in India. The state has about 26% share in proven limestone reserves in the country (IBEF : India Brand Equity Foundation 2020).

Air pollution caused by industries has been responsible for serious occupational health hazards and adverse effects. The Rajasthan Pollution Control Board (RSPCB) has been regularly tracking the impact of the industrial activities on air quality in Jaipur, Alwar, Ajmer, Bhiwadi, Jodhpur, Kota, Pali, and Udaipur.

Jaipur city, as one of the fastest growing cities of India, faces expanding urbanization, with traffic congestion, poor road conditions, poor control of industrial emission, and increase in air pollution (Dhamaniya 2004; Kala et al. 2014).

**Table 2** Sources of air pollutants

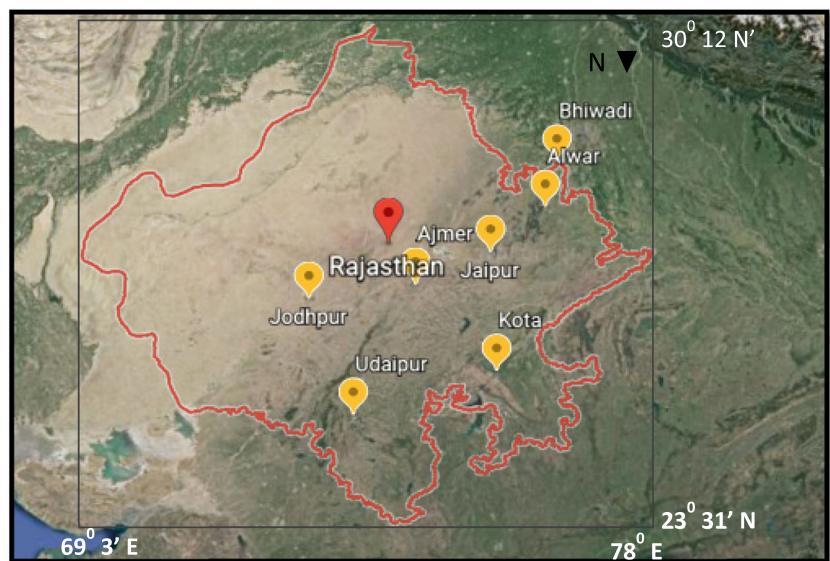
Name of the pollutant	Sources of pollutant	Study area	Reference
PM <sub>2.5</sub>	Burning of farm residue/open biomass burning, bio- and fossil-fuel combustion, household cooking, road dust, emission from vehicle exhaust, and industrial processes	India	Singh 2018; Guttikunda et al. 2016; Sharma and Dikshit 2016; Lelieveld et al. 2015; Chafe et al. 2014; Yadav et al. 2014
PM <sub>10</sub>	Burning of farm residue/biomass burning, cement industries, bio- and fossil-fuel combustion, industrial processes, wind-blown dust, building construction, lime kilns, slab polishing, marble stone devastating, vehicle travel on paved and unpaved roads, dust from open fields and farmlands.	India	Singh 2018; Sheikh and Najjar 2018; Yadav et al. 2014
SO <sub>2</sub>	Diesel driven personal vehicles, freight vehicles exhaust (vehicular traffic), diesel generator sets, burning of fossil fuels in industries  Industrial activities occurring in •iron and steel smelting unit •production of basic metals, metal products, and machinery •fertilizer unit •cement unit	India	Guttikunda et al. 2019; Sheikh and Najjar 2018; Pant and Chandramauli 2018; Gurjar et al. 2016
NO <sub>2</sub>	Industries, burning of fossil fuels, construction activities, and vehicular emission	India	Guttikunda et al. 2019; Pant and Chandramauli 2018; Sheikh and Najjar 2018; Sahu et al. 2012

The high concentration of air pollutants has worsened the human health (Tandon et al. 2008) and quality of life. The increased level of air pollutants in urban area is responsible for deficits in pulmonary functions, cardiovascular disease, neuro-behavioral effects, and mortality (WHO 2005a, b).

## Methodology

The impact of lockdown on air quality of seven selected cities of Rajasthan (Ajmer, Alwar, Bhiwadi, Jaipur, Jodhpur, Kota, and Udaipur) (Fig. 1) has been reviewed for two time periods.

**Fig. 1** Study area with location of selected cities: Ajmer, Alwar, Bhiwadi, Jaipur, Jodhpur, Kota, and Udaipur



- (a) Before lockdown period: 10 March 2020 to 20 March 2020  
 (b) During lockdown period: 25 March to 17 May 2020

The continuous ambient quality data for the selected cities have been acquired through the Central Pollution Control Board, New Delhi (CPCB). The data included five criteria air pollutants: (i) particular matter of size less than 2.5  $\mu\text{m}$  ( $\text{PM}_{2.5}$ ), (ii) particular matter of size less than 10  $\mu\text{m}$  ( $\text{PM}_{10}$ ), (iii) sulfur dioxide ( $\text{SO}_2$ ), (iv) nitrogen dioxide ( $\text{NO}_2$ ), and (v) ozone ( $\text{O}_3$ ) (CPCB 2020).

## Results and discussion

The results are depicted in the Fig. 2 and Fig. 3.

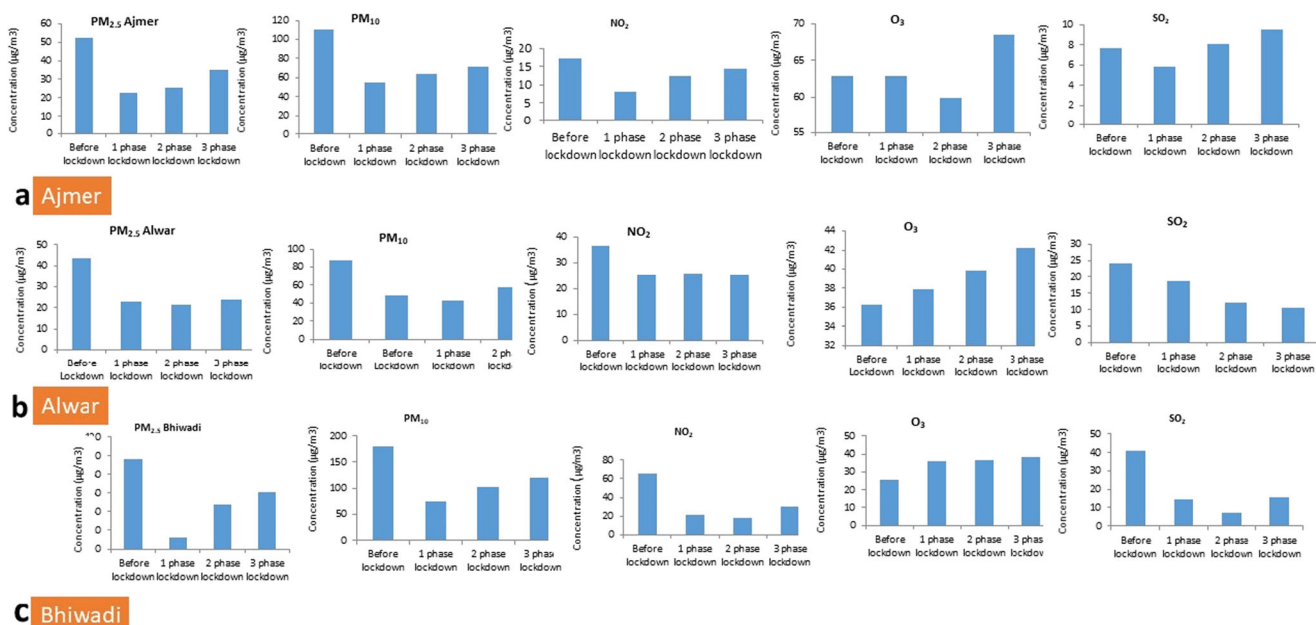
The temporal analysis of the variation in the levels of criteria air pollutants revealed that there was a significant decline in the concentration of all pollutants except for ozone ( $\text{O}_3$ ) in all the cities of Rajasthan under examination (Figs. 2 and 3); however, the concentration of ozone observed a decline in Jaipur city (Fig. 3a). The decrease in the concentration of the air pollutants was more significant in the first phase of the lockdown as compared with the next two phases of lockdown. This can be attributed to the relaxation provided in the later phases of lockdown.

As depicted in Figs. 2 and 3, there is no violation of the National Ambient Air Quality Standards (NAAQS for  $\text{PM}_{2.5}$  = 60  $\mu\text{g m}^{-3}$ ,  $\text{PM}_{10}$  = 100  $\mu\text{g m}^{-3}$ ,  $\text{SO}_2$  = 80  $\mu\text{g m}^{-3}$ ,  $\text{NO}_2$  = 80  $\mu\text{g m}^{-3}$  based on 24-hour average, and  $\text{O}_3$  = 100  $\mu\text{g m}^{-3}$  based on 8-h average) during the lockdown period in the seven cities of Rajasthan.

Furthermore, all criteria pollutants are within the NAAQS limit before lockdown except for  $\text{PM}_{10}$  in Jaipur, Jodhpur, Bhiwadi, and Ajmer with average concentrations being 105.256  $\mu\text{g m}^{-3}$ , 154.34  $\mu\text{g m}^{-3}$ , 178.54  $\mu\text{g m}^{-3}$ , and 110.30  $\mu\text{g m}^{-3}$  as presented in Figs. 2 and 3.

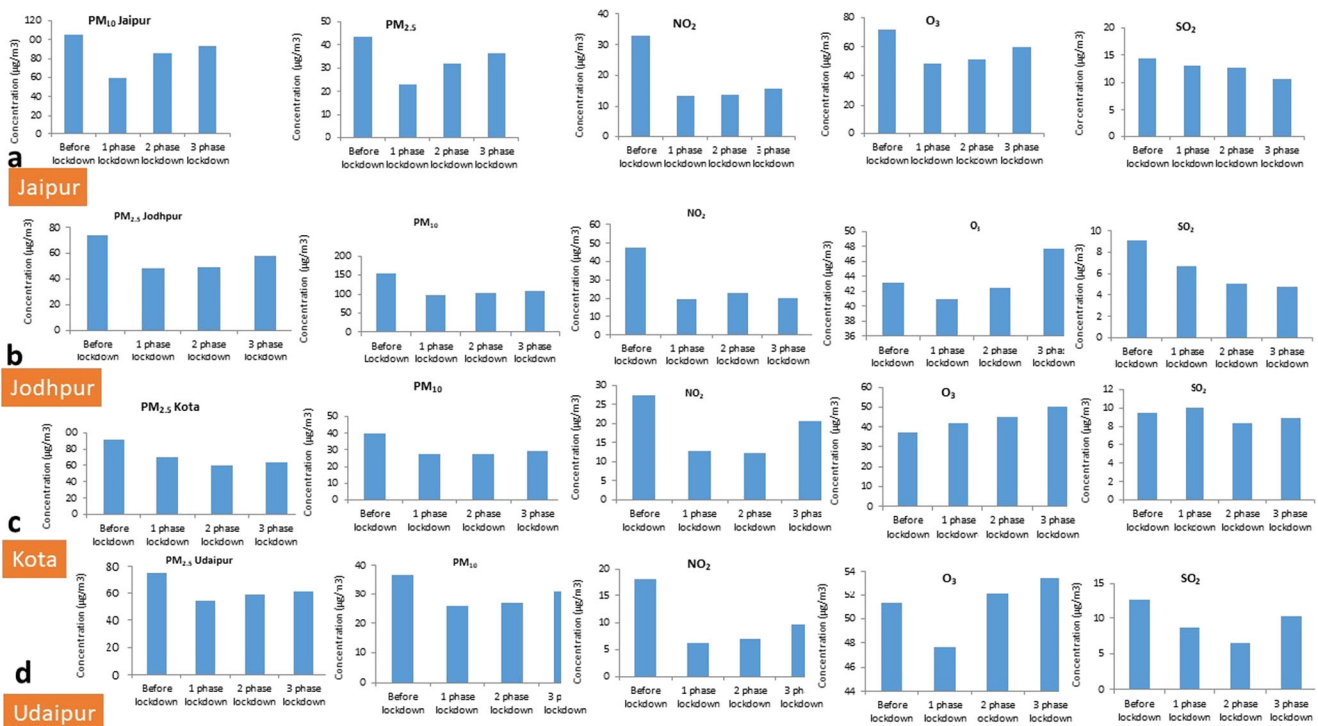
Table 3 represents the percentage change in all the criteria pollutants considered in the selected cities of Rajasthan for a period of assessment, i.e., before lockdown versus during lockdown (average of all the three phases of lockdown) amid Covid-19. The result of the analysis showed that the most significant dip was observed in the  $\text{NO}_2$  concentration, in all the seven cities of the Rajasthan with maximum decline of ~ 64% being observed in Bhiwadi city of Rajasthan, before and during lockdown duration in 2020. A similar decline in nitrogen dioxide concentration was also reported in China due to Covid-19 pandemic (Dutheil et al. 2020). The concentration of  $\text{SO}_2$  showed a noticeable change in Bhiwadi, Alwar, and Jodhpur. In Bhiwadi, maximum decline in concentrations of  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$ , and  $\text{SO}_2$  was observed, ~ 58.2% (178.54 to 98.74  $\mu\text{g m}^{-3}$ ), ~ 44.69% (95.98 to 40.09  $\mu\text{g m}^{-3}$ ), and ~ 69.90% (41.01 to 12.34  $\text{mg m}^{-3}$ ) respectively, during lockdown phase in comparison with that before the lockdown period.

Reports of other cities in India and China showed a similar pattern of decrease in concentration of the air pollutants except ozone. The concentration of ozone was found to be increased during the lockdown period in other parts of world (Xu et al. 2020; Jain and Sharma 2020). In the current study, the maximum percentage of increase (45%) in  $\text{O}_3$  was witnessed in Kota. In order to understand the unlikely trend in the change in concentration of ozone, let us see the photochemical reactions responsible for formation of ozone in the atmosphere (Fig. 3c).



**Fig. 2** Air pollutants in different cities before lockdown and after lockdown of three phases. (a) Ajmer, (b) Alwar, (c) Bhiwadi





**Fig. 3** Air pollutants in different cities before lockdown and after lockdown of three phases. (a)Jaipur (b) Jodhpur (c) Kota, and (d) Udaipur

Nitrogen oxides (NOx) and volatile organic compounds (VOCs) are referred as ozone precursors. The ambient concentration of ozone is governed by the mentioned precursors, temperature, solar radiations, wind speed, and other meteorological factors. As reported, ozone is produced by a complex reaction taking place among NOx and VOCs in the presence of sunlight (Srivastava et al. 2005; Lee et al. 2002). The present study area is urban part and thus falls under VOC-limited region of the country (Seinfeld and Pandis 1998). In a VOC-limited environment, the ozone accumulation is directed by the chemistry between the anthropogenic emission of NOx and ozone, beside the meteorological factors (Saini et al. 2017). Thus, the increase in concentration of ozone during lockdown period could be correlated to increased solar radiation and decrease NO<sub>2</sub> owing to favorability of the photochemical reaction (Fig. 4). More than 75% of nitrogen is released from activities like agriculture, transport (fossil-fuel

combustion), and industries [17], and during lockdown, there was a restriction in all the mentioned sectors, leading to lowering of the concentration of NOx emissions in VOC-limited environment, which could be correlated to the increase in concentration of ozone in most of the selected cities (Kim et al. 2018; Sicard et al. 2020; Shrestha et al. 2020; Sharma et al. 2016).

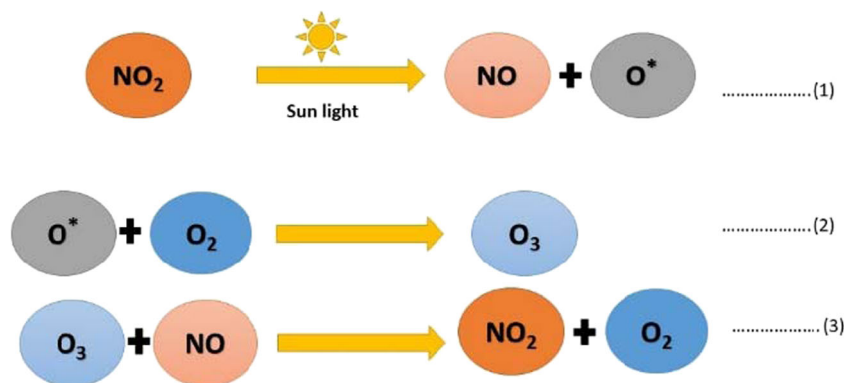
It is also documented that decrease in the concentration of PM causes more infiltration of solar radiation through the atmosphere. The presence of more solar energy enhances the photochemical activities, thereby increases O<sub>3</sub> production in the atmosphere (Dang and Liao 2019; Li et al. 2019).

Furthermore, the reduction in PM<sub>2.5</sub> levels during the lockdown period may also be credited to reduce NO<sub>2</sub> levels, an important factor in the formation of secondary PM (Jain and Sharma 2020). In addition to transportation, the other factors that resulted in a reduction in air pollution levels are shutdown

**Table 3** Percentage of change in the criteria pollutants of selected cities in Rajasthan, before and during lockdown amid Covid-19 (average of the three phases of lockdown)

Cities	Percentage change in PM <sub>2.5</sub>	Percentage change in PM <sub>10</sub>	Percentage change in NO <sub>2</sub>	Percentage change in ozone	Percentage change in SO <sub>2</sub>
Jaipur	− 24.97%	− 29.69%	− 56.18%	− 25.86%	− 15.68%
Bhiwadi	− 58.22%	− 44.69%	− 64.41%	+ 45.05%	− 69.91%
Alwar	− 47.33%	− 42.81%	− 30.22%	+ 10.19%	− 42.79%
Jodhpur	− 30.00%	− 33.49%	− 56.69%	+ 1.14%	− 38.96%
Kota	− 29.10%	− 29.341%	− 44.83%	+ 22.93%	− 3.47%
Ajmer	− 47.62%	− 42.69%	− 32.72%	+ 1.35%	+ 2.09%
Udaipur	− 22.52%	− 23.73%	− 57.98%	− 0.52%	+ 32.39%

**Fig. 4** Photochemical reactions of formation and decomposition of ozone



of industries and construction and demolition activities, depletion of road dust, refused burning, and reduction in electricity demand from thermal power plants.

The results are further analyzed based on the meteorological parameters. The meteorological parameters of the selected cities of Rajasthan are depicted in Table 4.

It is well-documented that the air quality is related to the meteorological parameters like wind speed, temperature, and relative humidity (Sharma et al. 2020). In the present study, we have summarized the wind speed and temperature before and after lockdown periods (Table 4). High temperature and high wind speed accelerate the dispersion of air pollutants in environment as compared with low temperature and calm wind speeds. As in Table 4, the average wind speed during the studied before lockdown period was 1.07 m/s in Jaipur, 0.82 m/s in Bhiwadi, 1.56 m/s in Alwar, 0.86 m/s in Jodhpur, 1.15 m/s in Kota, 3.4 m/s in Ajmer, and 2.34 m/s in Udaipur. The wind speed observed an incline in all the cities except Ajmer, during lockdown periods (the three phases). Similarly, all the selected cities witnessed a rise in temperature during lockdown period as compared with before lockdown period. Thus, the meteorological conditions were more favorable for air pollutant dispersion during lockdown period. Therefore, beside lockdown, meteorological parameters also showed an impact on the improvement of air quality in most of the cities.

### Special area of study: Bhiwadi

Bhiwadi is a city of Alwar district and is considered the industrial hub of Rajasthan. It has many small, medium, and large industries (Economic times 2012). Rajasthan State Industrial Development and Investment Corporation (RIICO) has improved its operations made Bhiwadi region of Alwar as an automotive hub by facilitating the establishment of different automobile manufacturing companies. The rapid industrialization and hence urbanization leads to evolution of different air

pollutants affecting the air quality. In a report on continuous ambient air quality data of eight cities of Rajasthan (RSPCB (Rajasthan State Pollution Control Board) 2018), the concentration of  $\text{PM}_{10}$  was found as the highest ( $201.24 \mu\text{g}/\text{m}^3$ ) at Bhiwadi among the eight monitored cities. Also  $\text{PM}_{2.5}$  ( $68.10 \mu\text{g}/\text{m}^3$ ) and  $\text{SO}_2$  ( $19.48 \mu\text{g}/\text{m}^3$ ) was reported as the highest in Bhiwadi that must be due to the various industries located in and around the city.

Due to restricted activities amidst lockdown, the effect on the air quality of Bhiwadi is most significant (Fig. 2c). We have taken Bhiwadi as a representative city of Rajasthan to further study the impact on air quality. We have performed Wilcoxon signed rank test with data of previous year 2019 (10 March–17 May) and this year 2020 (10 March–17 May) to assess the effects of lockdown on air quality parameters in Bhiwadi.

The test shows that for Bhiwadi, all the air quality parameters, except ozone, are statistically significant ( $p < 0.05$ ). All the parameters, except ozone, were found to be lower during March–May 2020 as compared with those during March–May 2019 (Table 5). For ozone ( $p > 0.05$ ), it signifies that the ozone concentrations in study period 2019 and 2020 are not significantly different ( $p$  value = 0.85) (69).

### Conclusion

The study of air quality during lockdown situation, when the anthropogenic activities were minimized, is an excellent chance to ascertain the impact of human activities on the worsening of the environment (Saadat et al. 2020). During lockdown, most of the activities including industrial, transport, and tourism were put on hold and thus showed an improvement in the air quality of the selected cities of Rajasthan.

The air quality of different seven cities of state Rajasthan showed a trend of decrease in concentration of all the pollutants (except ozone) during lockdown period as compared with that of before lockdown period. The increase in concentration

**Table 4** Meteorological parameters of Rajasthan from 10 March 2020 to 17 May 2020 (divided into four phases)

City	Jaipur		Bhiwadi		Alwar		Jodhpur		Kota		Ajmer		Udaipur	
	Wind speed (m/s)	Temperature (°C)	Wind speed (m/s)	Temperature (°C)	Wind speed (m/s)	Temperature (°C)	Wind speed (m/s)	Temperature (°C)	Wind speed (m/s)	Temperature (°C)	Wind speed (m/s)	Temperature (°C)	Wind speed (m/s)	Temperature (°C)
Before lockdown	1.07	23.81	0.82	19.96	1.56	27.48	0.86	24.39	1.15	27.48	3.4	23.39	2.34	Data not available
First phase lockdown	1.27	28.35	0.99	27.07	1.83	32.63	0.77	28.72	1.12	32.63	2.5	27.83	2.22	Data not available
Second phase lockdown	1.25	31.09	0.82	29.98	1.69	35.71	0.88	32.61	1.46	35.71	2.38	30.93	2.42	Data not available
Third phase lockdown	1.18	32.08	0.82	31.41	1.67	37.32	0.86	33.77	1.4	37.32	3.07	32.49	2.23	Data not available

**Table 5** Wilcoxon signed rank test on pollutants of Bhiwadi city

S. No.	Parameter	Z	p value
1	PM <sub>2.5</sub>	-6.27	0
2	PM10	-6.93	0
3	Ozone	-0.19	0.85
4	NO <sub>2</sub>	-0.69	0
5	SO <sub>2</sub>	-6.008	0

of ozone can be related to the decrease in NOx in the VOC-limited conditions. Furthermore, one of the severely polluted cities, Bhiwadi, showed the maximum dip in air pollutants. The Wilcoxon signed rank test on the city concludes that significant difference is absent between mean values of study period for ozone. But for other parameters (PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub>, and SO<sub>2</sub>), there is a significant difference in their mean values.

We can safely say that the Covid-19 pandemic is a lesson to learn from the benefits associated with the restriction of human activities during lockdown period not only in terms of safety but also as improvement in the air quality. As per the WHO report (WHO 2016), the deaths from air pollution share 7.6% of all the premature deaths, globally. The reduced pollution level can help nature to revive and may contribute in reduction of fatalities due to pollution.

The WHO reported that bringing down PM<sub>2.5</sub> levels by 25 µg m<sup>-3</sup> (from 35 to 10 µg m<sup>-3</sup>) would result in a reduction of 15% premature deaths (mortality) (WHO 2005a, b). Even though impact due to exposure to air pollution will not result in instantaneous mortality, and it is more of a chronic phenomenon. Therefore, immediate benefits would be more in terms of avoided morbidity and increased in healthy days. The lockdown was proven as an ideal strategy to tame pollution and its adverse effects on human health (Gautam 2020).

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