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RESEARCH ARTICLES

Effect of association of temperature and pollutant levels on COVID-19 spread over Jaipur

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Abstract

The association of temperature and air pollutants is a very prominent factor which significantly affects human health and may cause diseases such as respiratory illness, cardiovascular mortality in spreading of different pathogenic diseases. The pandemic due to covid-19 infection may be affected by temperature and concentration of pollutants. Jaipur is one of the most polluted cities in Rajasthan of India as per World Health Organization, 2016; also, Jaipur city has a hot semi-arid climate with extremely hot summers. This fact tempered us to examine the impact of the association of temperature and pollutants on corona-virus infection in humans over Jaipur. Analysis was conducted by correlating air pollutants (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO) on seasonal variations because the temperature is one of the major factors in changing seasons. Association between the number of Covid cases and temperature in Jaipur was observed during December 2019 to December 2020. Seasonal analysis indicated that the intensity of Covid-19 infection varied according to increase or decrease in temperature.

Keywords Temperature · Respiratory diseases · COVID-19 · Seasonal variations

Introduction

Air pollutants are liberated from various sources and contaminate the Earth's atmosphere by modifying physical, chemical, and biological processes. The contaminated air may degrade the indoor and outdoor areas and cause various communicable and non-communicable diseases. Globally every year, 7 million people die because of exposure to the high level of air pollutant concentrations (WHO 2018). Aerosol concentrations emitted from sources such as vehicular, industrial emissions, road dust, crop burning, and domestic, or construction activities are on the rise with ever-increasing population and expansion (Upadhyay et al. 2020). The increased level of air pollutants in the urban area is responsible for cardiovascular disease, neurobehavioral effects, mortality, and deficits in pulmonary functions (Manisalidis et al. 2020). Higher concentration levels of $PM_{2.5}$ and NO_2 have deleterious health effects with severe impact on lung functioning and respiratory systems (Gollakota et al. 2021).

Pollutant emission, transport, dispersion, chemical transformation, and deposition can be influenced by various meteorological variables such as temperature, humidity, wind characteristics, and vertical mixing (Bodor et al. 2020). Meteorology and anthropogenic emissions can change the persistence of huge environmental issues (Lalwani 2016). Therefore, climate change could significantly affect public health, especially in underdeveloped countries. Primary and secondary pollutants can boost climate change that in turn affects public health through more extreme temperatures (Tong and Ebi 2019). Recently, it has been seen that the climatic factors were responsible for spreading coronavirus caused Covid-19 (Bukhari et al.2020). The World Health Organization has declared Covid-19 as an infectious, pathogenic disease that is caused by contact with the respiratory droplets exhaled by the infected person. With the inception of the covid-19 pandemic, partial and complete lockdown were imposed to flatten the infection curve though some measures that have been taken during the pandemic like shutting down of schools, cinema halls, malls and restrictions on other activities including mass gatherings, funerals, weddings, etc. (Ranjan et al. 2020). In India, the partial lockdown

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was imposed after reported the first case of SARS-CoV-2 in Kerala (Gautam and Hens 2021). The Government of India imposed complete lockdown as 1st phase (21 days) from March 24th to 14th of April 2020. After that partial lockdown was recommended with some conditional relaxation from April 15th to 31st of May in 4 phases. After that, from June 2020 to November 2020, partial lockdown was implemented in unlock 1.0 to unlock 6.0 with different zones according to spreading of disease in particular place (Ghosal et al. 2020). Complete lockdown restricted all human mobility and economic activities while in partial lockdown, some necessary activities were allowed with partial restrictions like mass gathering, maintain distance and wearing mask etc.

Worldwide lockdown impact on air pollutant levels reduced its marginal level reported by Chelani and Gautam (2021) through worldwide restricted social and economic activities amidst lockdowns (Krecl et al. 2020). Epidemiological studies evidenced that ambient temperature is one of the major factors for the transmission of pathogenic diseases (Brumfield et al. 2021). A study on 122 cities in China reported that mean temperature affected the number of Covid-19 cases with a margin of 3 °C (Xie and Zhu 2020). The correlation analysis also showed that the temperature reduces monthly by 2 °C with decreasing pollutant concentrations by 51–72% in megacities such as Delhi, Kolkata, Mumbai, and Chennai (Pal et al. 2022). Rajasthan is also reported as a highly polluted state and has the high death rate due to exposure to ambient air pollutants (Syed 2018). Hence, we carried out this study to determine the variability of respiratory pathogenic diseases SARS Covid-19 due to its relationship with temperature and pollutant concentrations in Jaipur city.

Materials and methods

Study region

Koppen's climate classification divides the area based on seasonal precipitation and temperature patterns as A (tropical), B (dry), C (temperate), D (continental) and E (Polar). If the annual precipitation is < 50%, it would be noted as BW (arid: desert climate), while > 50% annual precipitation would be represented by BS (Semi-arid climate). Regarding temperature, if it is low latitude climate, denoted by "h" (average annual temperature above 18 °C (64.4°F)) and "H" is for high latitudes (Singh and Singh 2022). Rajasthan state is very hot and dry; the largest parts are classified as hot desert (BWh) and remaining are classified as semi-arid climate (BSh). In the winter season, temperature ranges from 8–28 °C, while in the summer, temperature reaches 40–50 °C. Resultantly, a dry environment remains in entire state. The present study was focused on Jaipur, one of Rajasthan's most popular cities and the capital of Rajasthan state, located at 26° 55′ 0" N, 75° 49′ 0" E. Jaipur city covers an area of 11,117 square kilometers with a population density of 470 persons per square kilometer (Popli et al. 2021) (Fig. 1).

Data collection

The rationale behind the selection of Jaipur city is the rapidly growing population in recent years which leads to an increase in vehicular and industrial pollution. To achieve the aim of this study, we have considered the study period from December 2019 to December 2020 during the arrival and peak of Covid 19 cases. The daily data of $PM_{2.5}$, PM_{10}, NO_2, SO_2 & CO were archived from CPCB website (http://cpcb.nic.in) for Adarsh Nagar, Jaipur for the period of

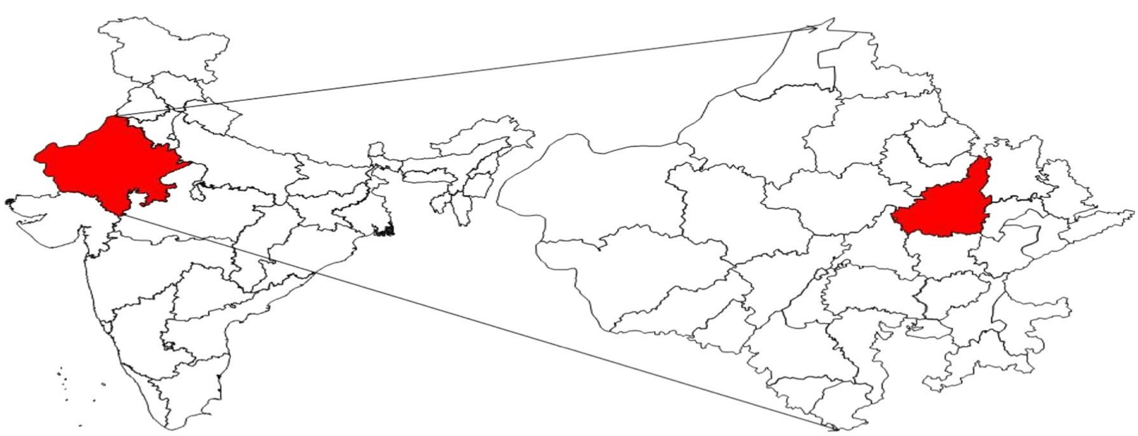

Fig. 1 Map of the location: India ⟶ Rajasthan ⟶ Jaipur city

December 2019 to December 2020. Temperature data was stored from 'OGIMET' (www.ogimet.com) during December 2019 to December 2020. The confirmed cases of covid-19 in Jaipur were obtained from the Ministry of Health and Family Welfare, Government of India (https://www.mohfw.gov.in) during April 2020 to December 2020 because the first wave of Covid-19 occurred during the month of March and confirmed covid cases were reported from April and gradually survived up to December 2020 in India. The details of lockdown during the study period have been given in Table 1.

To the best of our knowledge, this is the first study through which we revealed the seasonal impact of temperature, particulate pollutants, and gaseous pollutants on Covid-19 over Jaipur city.

Data analysis

We analyzed the variability of Covid-19 confirmed cases and pollutant concentrations as well as one of the meteorological variables, temperature, along with the linkage between them. Further, the correlation analysis was conducted for Covid-19 confirmed cases with daily mean temperature values and daily mean pollutant concentrations. The results were compared with NAAQS (National Ambient Air Quality Standards) regulation 2009, prescribed by Central Pollution Control Board (CPCB) (http://cpcb.nic.in) given in Table 2. The seasonal fluctuations in temperature daily data and the impact of particulate matter (PM_{10}, $PM_{2.5}$) and gaseous pollutants (NO_2, SO_2, CO) on Covid-19 confirmed cases were also examined during three seasons: MAM (March, April, May), JJA (June, July, August) and SON (September, October, November).

Table 1 Lock down table with activities

Date	Complete/partial lockdown	Activities
25 March–14April (phase-1)	21 days/complete lockdown	All necessary services and mobility activities restricted
4 May–17 May (phase-3)	14 days/complete lockdown	Conditional relaxation (zones are divided with spreading of disease) with night curfews
18 May–31May (Phase-4)	14 days/ complete lockdown	Conditional relaxation (zones are divided with spreading of disease) with night curfews
June 2020 (Unlock1.0)	30 days/partial lockdown	Lockdown only in Containment zones with economic focus
July 2020 (Unlock2.0)	31 days/partial lockdown	Lockdown with limited travel restrictions
August 2020 (Unlock3.0)	31 days/partial lockdown	Inter and intrastate travel permitted with removing night curfews
September 2020 (Unlock4.0)	30 days/partial lockdown	Allowed Mass gatherings with limited population with wearing mask
October 2020 (Unlock5.0)	31 days/partial lockdown	Public transportation allowed with some restrictions for economic support
November 2020 (Unlock6.0)	30 days/partial lockdown	Allowed some more activities with partial opening of schools

Table 2 National ambient air quality standards

S. no.	Pollutants	Time weighted average	Concentration in ambient air	
			Industrial, residential, rural, and other areas	Ecologically sensitive area (notified by central government)
1	PM_{10} μg/m^3	Annual	60	60
		24 h	100	100
2	$PM_{2.5}$ μg/m^3	Annual	40	40
		24 h	60	60
3	NO_2 μg/m^3	Annual	40	30
		24 h	80	80
4	SO_2 μg/m^3	Annual	50	20
		24 h	80	80
5	CO mg/m^3	8 h	02	02
		1 h	04	04

Results and discussion

Time series of PM_{10}, $PM_{2.5}$, NO_2, SO_2 & CO

The maximum $PM_{2.5}$ concentration before lockdown was recorded 50.83 μg/m^3 in December 2019 and it gradually decreased up to16.15 μg/m^3 during the month of September 2020 after lockdown. The concentration again increased and reached up to 162.14 μg/m^3 in the month of November 2020. In the same pattern, PM_{10} concentrations were observed as 99.61 μg/m^3 in December 2019 and 209.35 μg/m^3 in November 2020, and it declined at lowest level up to 28.05 μg/m^3 in August 2020. It has been clearly observed that before lockdown (March 2020) the concentrations were higher than the NAAQS standards (Table 2). The lowest particulate pollutant concentrations during the Covid-19 period were also observed due to decreased emissions (Sharma et al. 2020). Maximum concentrations of gaseous pollutants were recorded as 80.4 μg/m^3 (February 2020),16.79 μg/m^3 (February 2020) &1.28 mg/m^3 (December 2019) for NO_2, SO_2 and CO respectively. NO_2 concentrations were greater while SO_2 and CO concentrations were less than the prescribed NAAQS standards. NO_2 concentration showed the lowest peak in May 2020 with 7.7 μg/m^3 and reached the highest in October 2020 with 97.17 μg/m^3. This results that lockdown shows greater impact through which lower concentrations in May 2020 and reached to higher concentrations in October 2020. SO_2 concentration was 6.41 μg/m^3 in the month of May 2020 and reached to maximum 14.26 μg/m^3 in November 2020, when the first wave of lockdown commenced to end.CO concentrations were recorded as 0.4 mg/m^3 in August 2020, whereas it gradually increased up to 2.16 mg/m^3 in November 2020. Here in the beginning of lockdown the NO_2 and CO concentrations were less than the NAAQS standards while SO_2 concentrations were greater than the standards (Fig. 2). This might be due to airborne particulate matter which signifies a complex mixture of organic and inorganic substances (Rani et al. 2011). Several studies reported that the chemical and biological elements may be altered by PM concentration mainly $PM_{2.5}$ which diffuses into sensitive regions of the respiratory system and may cause multiple allergies and respiratory illnesses and premature mortality (Wu et al. 2020). Jaipur is one of the fastest-growing urban cities in India thus influenced with high traffic obstruction and industrial emissions that increase the air pollution (Saigal et al. 2021). On the other hand, high temperature and high wind speed increase the dispersion of particulate pollutants in the environment. Hence anthropogenic emission significantly decrease ambient air pollutants' concentrations which is reflected in seasonal variations in seasonal pollutants before and after lockdown periods (Lonati and Riva et al. 2021).

Seasonal variations in temperature and impact on Covid-19 cases

On the onset of Covid-19 pandemic, the cases were stable but slightly increasing with increasing temperature in the summer season MAM. In the month of April, the cases were reported around 500–1000 with the temperature 27.7 °C and increased up to 1700–2000 at 35–40 °C. During monsoon season JJA, the temperature ranged between 27.4 °C

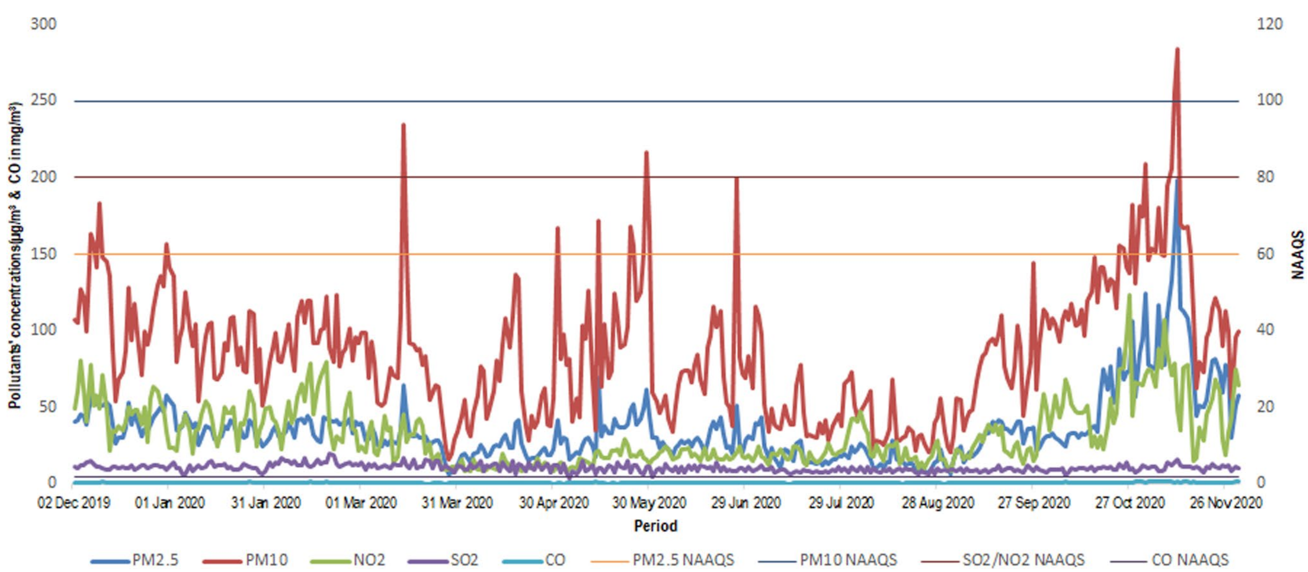

Fig. 2 Time Series of particulate pollutants and gaseous pollutants during December 2019–December 2020

-33.6 °C from June to mid of July. Around 2027 cases were reported in the beginning of June at 27.4 °C whereas 4222 cases were reported at 33.6 °C in mid-July. Due to rainfall activity the temperature decreased from mid-July, whereas the covid cases continued to rise. In the post monsoon season (SON), the temperature gradually decreased from 26.2 °C in the beginning of August up to 18.2 °C till the end of November. There were around 10,791 cases reported at 26.2 °C temperature in August while the cases increased up to 43,300 till last week of November at 18.2 °C. (Fig. 3). Biphasic relationship is named between the daily averages of Covid19 and temperature, as temperature increases the covid cases are decreased (Shi et al. 2020). Wang et al. (2020) observed that fluctuating temperatures are responsible for increasing Covid19 transmission, while Pal et al. (2022) revealed that temperature and humidity enhance the severity of diseases.

Seasonal variations in particulate pollutants (PM_{10} & $PM_{2.5}$) and impact on Covid-19 cases

In the pre-monsoon season MAM, the lower concentrations of $PM_{2.5}$ (21.29 μg/m^3) and PM_{10} (38.56 μg/m^3) were observed with less effect on Covid-19 cases as 808 and 859 respectively. In monsoon season JJA, the PM concentrations were gradually decreased from 51.09 μg/m^3 to 7.3 μg/m^3 for $PM_{2.5}$ and from 199.62 μg/m^3 to 20.38 μg/m^3 for PM_{10}. On 1st June 2020, the Covid-19 cases were recorded as 2069 and on 31st August, they were increased to 10,791. As of the post-monsoon season SON, the Covid cases were increasing with the decreasing of particulate pollutants. In the month of September, the concentrations were decreased for $PM_{2.5}$ (6.79 μg/m^3) and PM_{10} (20.75μ gm/m^3). Covid-19 cases were increased from 11,099 on 1st September 2020 to 47,771 till 31st of November which may be a consequence of higher particulate pollutant concentrations in November. During winters, the covid cases were increased with increasing PM concentration (Fig. 4). The relationship between PM concentrations and communicable diseases was also documented in recent studies (Toppi et al. 2020). The Covid-19 cases were reported as decreased positively with decreased concentrations of $PM_{2.5}$ to PM_{10} (Zoran et al. 2020). Another study also reported that the relationship of Covid19 is an visible evil twin while PM concentrations found to be unseen twin by Laxmipriya and Narayana (2021).

Seasonal variations in gaseous pollutants (NO_2, SO_2 & CO) and impact on Covid-19 cases

In summer season MAM, the lowest peak of NO_2 concentration 8.18 μg/m^3 was recorded on 30 April 2020 and highest peak 29.74 μg/m^3 on 22 May 2020. Lowest SO_2 concentration was reported as 3.58μgm/m^3 on 5th May 2020 and highest concentration 14.67μgm/m^3 was recorded on 9th May 2020. CO values were recorded very low as 0.7 mg/m^3 in mid of May 2020. There were 808 Covid-19 cases that were reported on 26th April 2020 reached to 1991 on 31st May 2020. In summer season, the Covid-19 cases rose with the increasing concentrations of NO_2, SO_2 and CO. It is obvious from the results that gaseous pollutants have very less effect on Covid-19 cases during lockdown. In monsoon season JJA, lowest concentration of NO_2 (10.21 μg/m^3) on 31st August 2020 and highest concentration of NO_2 (47.53 μg/m^3) were reported on 4th August 2020. The highest concentration of SO_2 was recorded as 13.9 μg/m^3 on 20th June 2020 whereas the lowest value was 6.34 μg/m^3 on 27th August 2020. The lowest CO (0.4 mg/m^3) concentration on 6th August 2020. The number of Covid-19 cases was recorded as 6146 in the month of August. These results

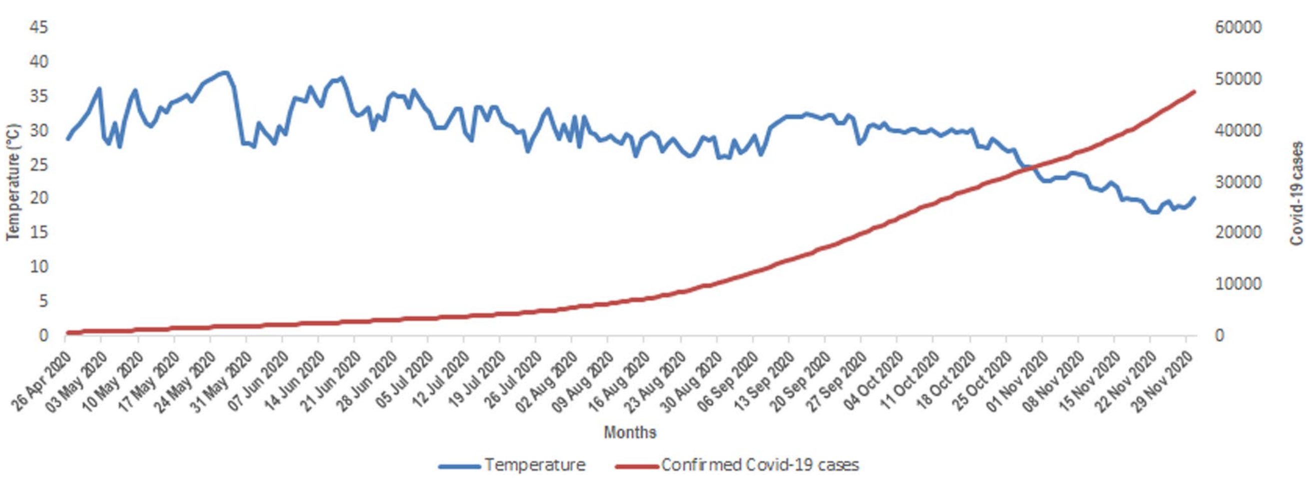

Fig. 3 Seasonal impact of temperature on Covid-19 cases during Summer, Monsoon & post monsoon seasons (MAM, JJA, SON)

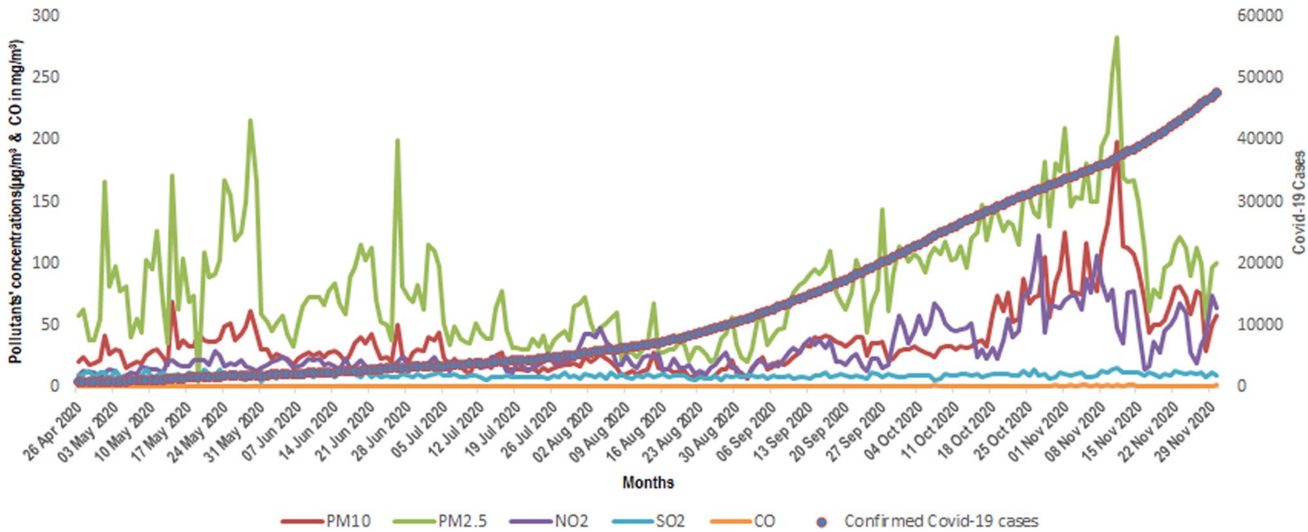

Fig. 4 Seasonal impact of PM_{10}, $PM_{2.5}$, NO_2, SO_2 & CO on covid cases during summer, monsoon, and post monsoon season (MAM, JJA & SON)

indicate that Covid-19 cases were not impacted in monsoon season. In post-monsoon period SON, the lowest value of NO_2 12.97 µg/m^3 on 24th September 2020 whereas the highest peak was reported at 123.3 µg/m^3 on 27th October 2020. In the post-monsoon period (SON), NO_2, SO_2 and CO concentrations varied with increased covid cases. Lowest value of NO_2 was 12.97 µg/m^3 on 24th September 2020 whereas the peak was reported at 123.3 µg/m^3 on 27th October 2020 with 19,001 cases and 32,030 cases respectively. The highest concentrations of SO2 (16.31 µg/m^3) were noted with 37,185 cases on 11th November 2020, whereas 24,571 cases were observed at lowest SO_2 concentration (5.77 µg/m^3) on 7th October 2020.There were 35,660 cases recorded at highest CO concentration (2.16 µg/m^3) on 7th November 2020 and the lowest concentrations of CO (0.4 µg/m^3) were seen with 12,716 covid cases on 6th September 2020.Therefore, it is observed that the effect of concentrations of NO_2, SO_2 and CO in pre-monsoon (summer), monsoon and post-monsoon seasons on spreading Covid-19 cases were less effective comparing to PM concentrations(Fig. 4).

In the southern and central part of India a clear decrease was seen in NO_2 and CO concentrations. Sharma et al. reported that decline of all pollutant concentrations was recorded in the lockdown period compared to previous years (Sharma et al. 2020). Similar pattern was observed for Aerosol Optical Depth (AOD), NO_2 and SO_2 for Southeast Asia, Europe and USA and detected the substantial diminutions in AOD and NO_2 emissions in the Covid period (Acharya et al. 2021). A substantial decline was reported in concentrations of PM, NO_2, CO and SO_2 with mixed variations (Singh et al. 2020).

Correlation analysis for temperature and pollutants

Figure 5 showed the correlation analysis for temperature and pollutants to assess the status of Covid-19 confirmed cases. Seasonal variability in all the parameters was observed with magnitude, however, confirmed cases were noticed to be more prone with temperature and $PM_{2.5}$ in comparison with other variables. Temperature showed a negative correlation during the monsoon (− 0.680) and post-monsoon season (− 0.851), whereas a positive correlation has been noted during the pre-monsoon season (0.460). From these factors, the number of positive cases were found to be associated with the rise in temperature over the study area. During the monsoon season, the number of positive cases got affected with wind-driven moisture advection rainfall activities and dipole situation noted with the negative correlation. The negative correlation has strongly increased with the decrease in the temperature in the post-monsoon season. Hence, an association of temperature with the positive number of cases is noticed over the study region.

Seasonal variability of $PM_{2.5}$ and PM_{10} showed a see-saw pattern holding negatively correlated (− 0.611, − 0.491) in monsoon and conversely positively correlated in pre-monsoon (0.663, 0.550) as well as in the post-monsoon (0.637, 0.507) respectively. A possible reason for the negative association in monsoon for particulate matter is the decrease of its concentration during the season due to rainfall. Therefore, an indirect effect of rainfall revealed the relationship between the positive number of cases and the particulate matter. NO_2 does not show any seasonal variability but is positively correlated (0.652) in the pre-monsoon season. SO_2 possessed a negative association (− 0.0.010) during

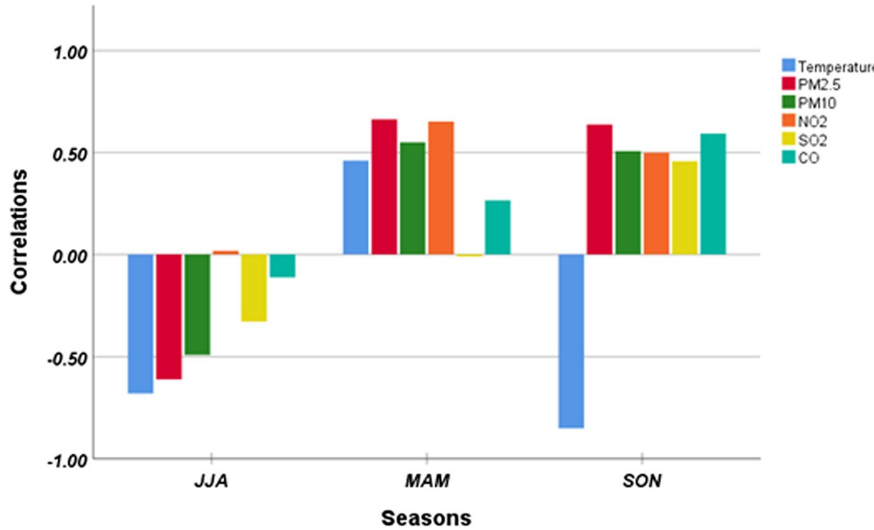

Fig. 5 Seasonal correlations for temperature, PM_{10}, $PM_{2.5}$, NO_2, SO_2 and CO during summer, monsoon, and post monsoon season (MAM, JJA and SON) [Correlation is significant at the 0.01 level (2-tailed)]

monsoon and a positive correlation (0.457) in the post-monsoon season. CO exhibited a negative correlation (−0.111) in the monsoon season and a positive correlation (0.265 and 0.593) in the pre-monsoon and post-monsoon season. Similar results were reported by Bashir et al. (2020) and revealed that average temperature, minimum temperature, and air quality were significantly associated with the COVID-19 pandemic. An increase in the daily newly confirmed cases (~129) in Wuhan was also observed with the association of decreasing temperature (Hu et al. 2021).

Conclusion

Climate change is the environmental change that produces a variety of natural disasters such as temperature fluctuations, severity of floods, and impact of droughts etc. The association between temperature and pollutants has been seen to be very strongly effective. This association affects human health, causing physiological issues such as respiratory illness, cardiovascular mortality, and the spread of many pathogenic diseases. Particularly in the case of Jaipur, we have analyzed the relationship between temperature and pollutants such as $PM_{2.5}$, PM_{10}, CO, NO_2, and SO_2 and observed the significant influence on infectious diseases, Covid-19. In Jaipur, the intensity of pathogenic diseases such as Covid-19 increases when the temperature rises or falls due to the impact of seasons during December 2019 to December 2020. In the month of November, the highest number of cases (43,300) were reported at low temperature levels (18.2 °C). This study may assist the decision makers to formulate the policies by assuming expected outcomes. Also expected outcomes may be postulated for public knowledge in scenarios such as Covid-19 and related disorders.

Humidity is also one of the important meteorological factors which shows impact on covid cases. Recent studies revealed the reduction of 3.08% in daily new cases and 1.19% in daily deaths at low temperature (1 °C) and low relative humidity (1%). Those are associated with 0.85% of new covid cases and 0.51% of new death cases reported up to March 27, 2020 (Wu et al. 2020). Therefore, the relation of covid cases with temperature and humidity is very prominent. But the same study shows that temperature enhances the impact on covid cases more than humidity. For instance, 1 °C of diurnal temperature increases 14.2% confirmed cases in 2 days while 1% relative humidity increased 19.92% confirmed cases in 4 days.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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