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Review

COVID-19 and air pollution and meteorology-an intricate relationship: A review

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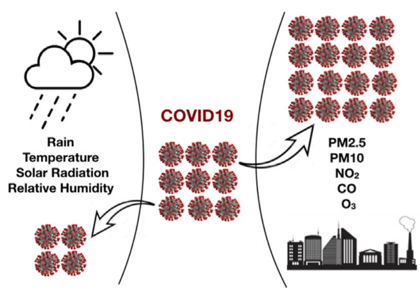
HIGHLIGHTS

- Aerosol containing SARS-CoV-2 generated by sneeze and coughs are major source of spread of virus.
- Viability and virulence of SARS-CoV-2 stuck on the surface of particle is not yet confirmed.
- Particulate matter and Gaseous pollutant have caused more COVID19 cases and mortality.
- Decline in number of cases with rising temperature/Humidity were observed.
- Air quality immensely improved due to lockdown.

GRAPHICAL ABSTRACT



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ABSTRACT

Corona virus is highly uncertain and complex in space and time. Atmospheric parameters such as type of pollutants and local weather play an important role in COVID-19 cases and mortality. Many studies were carried out to understand the impact of weather on spread and severity of COVID-19 and vice-versa. A review study is conducted to understand the impact of weather and atmospheric pollution on morbidity and mortality.

Studies show that aerosols containing corona virus generated by sneezes and coughs are major route for spread of virus. Viability and virulence of SARS-CoV-2 stuck on the surface of particulate matter is not yet confirmed. Studies found that an increase in particulate matter concentration causes more COVID-19 cases and mortality. Gaseous pollutant and COVID-19 cases are positively correlated.

Local meteorology plays crucial role in the spread of corona virus and thus mortality. Decline in number of cases with rising temperature observed. Few studies also find that lowest and highest temperatures were related to lesser number of cases. Similarly humidity shows negative or no relationship with COVID-19 cases. Rainfall was not related whilst wind-speed plays positive role in spread of COVID-19. Solar radiation threats survival of virus, areas with lower solar radiation showed high exposure rate.

Air quality tremendously improved during lockdown. A significant reduction in PM10, PM2.5, BC, NOx, SO_2, CO and VOCs concentration were observed. Lockdown had a healing effect on ozone; significant increase in its concentration was observed. Aerosols Optical Depths were found to decrease up to 50%.
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Contents

1. Introduction

COVID-19 pandemic, also known as the corona virus pandemic, is an ongoing pandemic of Corona Virus Disease 2019 (COVID-19) caused by Severe Acute Respiratory Syndrome Corona Virus 2 (SARS-CoV-2) (WHO, 2020a). The outbreak was identified in Wuhan, China, when the very first case was reported in December 2019 (WHO, 2020b). The World Health Organization declared this outbreak a Public Health Emergency of International Concern on 30 January, and a pandemic on 11 March (WHO, 2020c,d). As of September 5, 2020, about 27 million cases have been reported across 188 countries and territories, resulting in more than 880,000 deaths. More than 19 million people have recovered (JHU, 2020). The virus is primarily spread between people during close contact, often via small droplets produced by coughing, sneezing, and talking. The droplets usually fall to the ground or onto surfaces rather than remaining in the air over long distances. People may also become infected by touching a contaminated surface and then touching their face. On surfaces, the amount of virus declines over time until it is insufficient to remain infectious, but it may be detected for hours or days. It is most contagious during the first three days after the onset of symptoms, although spread may be possible before symptoms appear and in later stages of the disease.

Wuhan the epicenter of COVID19 was quarantined on January 23, 2020 stopping travel in and out of Wuhan (New Asia, 2020). By January 24, 2020, a total of 15 cities in Hubei, including Wuhan, were placed under similar quarantine measures (Deutsche Welle, 2020). Before quarantine began around 5,000,000 people left Wuhan to various parts of world and China (ABC News, 2020). This led to the infiltration of corona virus to different cities across the globe. To control and contain this pandemic, countries across the world started closing various activities phase-wise or at-once in the form of lockdown. The first country where partial lockdown began was China. After China, COVID19 overpowered Italy drastically. This led to almost nationwide lockdown in Italy from March 9, 2020 (Sylvers and Legorano, 2020). This was followed by Iran, where lockdown came into existence form march 14, 2020 (www.garda.com, 2020). By the end of March 2020 most of the nation across the world were forced to lockdown almost all the activities, putting human life to an absolute halt.

India too slightly delayed, but went through a similar kind of phase. First confirmed case of COVID-19 in India was reported on January 30, 2020 from Kerala's Thrissur district where a student who had returned home from Wuhan University in China was declared Corona Positive (Rawat, 2020). Till February 2020 there were only three cases of COVID-19 confined to Kerala state only and all were returnees from Wuhan, China (Rawat, 2020; The Weather Channel, 2020). But in March 2020 numbers of cases rose steeply and by third week over 550 people were declared COVID-19 positive. This led to a nationwide lockdown imposition from March 25, 2020 (News Channels, 2020).

This almost global lockdown played a crucial and important role in the improvement of air quality but on the other hand many studies showed cities with worst air quality suffered too much due to COVID-19 pandemic (Wu et al., 2020). This resulted into publication of number of articles across the globe to understand the effect of COVID-19 pandemic lockdown on the environment. Many other important studies were also carried out to understand the pathogenicity, an important factor to understand the mortality and morbidity, of corona virus due to various pollution and meteorological parameters (Huang et al., 2020).

In this review article an attempt has been made to understand the effect on mortality and number of cases due to pollution and weather parameters as well as impact of lockdown due to COVID-19 pandemic on the environment.

2. Corona virus in ambient air

There are three major aspects or rather concerns about corona virus's viability and virulence as an air pollutant.

2.1. SARS-CoV-2 associated aerosols- generated from coughs and sneezes

When the virus becomes suspended in droplets of smaller than 5 μm, known as aerosols, it can stay suspended for about half-hour, before drifting down and settling on surfaces where it can linger for hours. Coughs, sneezes, and even breathing generate aerosols (Tang et al., 2011; Pan et al., 2017; Atkins et al., 2020). These activities can result in spread of aerosols (small liquid droplets) in the air over various distances, and in some cases distances greater than 2 m. Depending on the room's airflow, small droplets in rooms with no airflow can remain suspended for periods of seconds to minutes, but with proper airflow these droplets are displaced and diffused even faster (Wei and Li, 2016; Bourouiba, 2020; JNIID, 2020, NHK documentary, 2020). Many factors contribute to the spread of airborne SARS-CoV-2. The infectious dose required to become infected with COVID-19 is unknown. Because of the potential to be exposed to droplets, surgical masks and eye protection is essential if within 2 m of the patient and may be advisable if in close proximity to a coughing or sneezing patient. In studies carried out in Wuhan, China, Italy, and New York City, from January 23 to May 9, 2020 found that airborne transmission is highly virulent and represents the dominant route to spread the disease (Zhang et al., 2020). Once the particles settle on different surfaces chances of the survival of the virus are strongly affected by droplet volume, contact angle, ambient temperature, and humidity (Bhardwaj and Agrawal, 2020).

2.2. SARS-CoV-2 associated pollutant particles

Tests conducted in Italy have found SARS-CoV-2 virus that causes COVID-19, can cling to air pollutants. However, it is yet not confirmed whether the virus remains viable and virulent on the particulate matter surfaces. Preliminary findings from the study suggest that if weather conditions are stable and concentrations of particulate matter (PM) are high, the virus could create clusters with PM (Bontempi, 2020; Domingo and Rovira, 2020).

Another study led by the University of Bologna and University of Trieste was conducted by collecting PM10 (respiratory particles) from Bergamo in northern Italy's Lombardy region where highest number of COVID-19 cases were recorded. This is an area also characterized by high concentrations of PM. Data till April 12 showed about 30% of COVID-19 positive people lived in Lombardy. The research team conducted their studies on 34 PM10 samples from an industrial area in Bergamo collected with air samplers over a period of three weeks from February 21 to March 13. The study found several samples tested positive for SARS-CoV-2 gene markers (Setti et al., 2020; Focus on COVID-19, 2020).

2.3. SARS-CoV-2 airborne without any substrate

There is no evidence to suggest that the virus is airborne, there are other viruses such as chicken pox which can easily be transported via air current and do not require droplets to contact the eyes or nose. The novel corona virus is not in this category of viruses (Yao et al., 2020).

3. Effect of air pollution on COVID-19 mortality

So far many studies have been conducted across the globe primarily in worst COVID-19 affected countries to understand the impact of various parameters of air pollution on COVID-19 mortality and number of cases (Table 1).

3.1. Particulate matters and COVID-19

In a study carried out in the United States to understand the exposure to air pollution and COVID-19 mortality, found that an increase of only 1 $\mu g/m^3$ in PM2.5 is associated with an 8% increase in the COVID-19 death rate (95% confidence interval [CI]: 2%, 15%). For this study COVID-19 death counts were collected for more than 3000 counties in the United States (representing 98% of the population) up to April 22, 2020 from Johns Hopkins University, Center for Systems Science and Engineering Corona virus Resource Centre (Wu et al., 2020). Another study done in 120 cities of China to understand the relationship between increase in particulate matter (PM2.5 and PM10) concentration and COVID-19 mortality showed that an increase in 10 $\mu g/m^3$ PM2.5 and PM10 results in 2.24% (95% CI: 1.02 to 3.46) and 1.76% (95% CI: 0.89 to 2.63) increase in the daily counts of confirmed cases, respectively (Zhu et al., 2020).

In one of the studies carried out in 71 Italian provinces observed that chronic exposure to atmospheric PM2.5 and PM10 represent a favorable context for the spread of virulence of the SARS-CoV-2 within a population subjected to a higher incidence of respiratory and cardiac affections (Fattorini and Regoli, 2020). In yet another discussion based study carried out in the Middle Eastern countries focusing indoor environment, it was concluded that habitual indoor burning of in-cense sticks which is the major source of PM10 and PM2.5 could facilitate the transmission of SARS-CoV-2 virus droplets and particles in indoor environments. In fact, it increases the spread of the virus via inhalation (Amoateya et al., 2020). A study conducted in northern Italy to understand the Potential role of PM10 in the spreading of COVID-19 found that PM10 daily limit value exceedances were a significant predictor ($p < 0.001$) of infection in univariate analyses. Less polluted Provinces had a median of 0.03 infection cases over 1000 residents, while most polluted provinces had a median of 0.26 cases over 1000 residents (Setti et al., 2020). The effects are illustrated in Fig. 1.

3.2. Gaseous pollutants and COVID-19

A study was conducted to understand the relationship between COVID-19 and tropospheric NO_2 distribution of 66 administrative regions in Italy, Spain, France and Germany. Results show that out of the 4443 fatality cases, 3487 (78%) were in five regions located in north Italy and central Spain. Additionally, the same five regions show the highest NO_2 concentrations combined with downwards airflow which prevents an efficient dispersion of air pollution (Ogen, 2020).

In another study conducted to understand the effect of SO_2, CO, NO_2 and O_3 pollution and COVID-19 mortality, it was found that a 10 $\mu g/m^3$ increase in NO_2, and O_3 result in 6.94% (95% CI: 2.38 to 11.51), and 4.76% (95% CI: 1.99 to 7.52) increase in the daily counts of confirmed cases, respectively. It was also noticed that 1 $\mu g/m^3$ increase in CO was associated with 15.11% (95% CI: 0.44 to 29.77) increase in the daily counts of COVID-19 confirmed cases. However, SO_2 was negatively associated with COVID-19 resulting in 7.79% decrease (95% CI: −14.57 to −1.01) in COVID-19 confirmed cases with a 10 $\mu g/m^3$ increase in SO_2 concentration (Zhu et al., 2020). Again the effects are illustrated in Fig. 1.

4. Weather conditions and COVID-19

Various studies across the world demonstrated that different climate parameters such as temperature, humidity, sunshine etc. have significant impact upon the number of COVID 19 cases and mortality caused due to this (Table 2).

Table 1
Effect of various pollutants on number of COVID19 cases and mortality.

S. No.	Parameter	Country	Variation in pollution parameter	Effect
1	PM2.5 & PM10	USA (3000 counties)	1 μg/m^3 increase in PM2.5	8% increase in the COVID-19 death rate (Wu et al., 2020)
		China (120 cities)	10 μg/m^3 increase in PM2.5 and PM10	2.24% and 1.76% increase in the daily counts of confirmed cases respectively (Zhu et al., 2020)
		Italy (71 provinces)	Chronic exposure to atmospheric PM2.5 and PM10	Favorable for the spread of virulence of the SARS-CoV-2 (Fattorini and Regoli, 2020)
		Middle Eastern countries	Elevated indoor PM2.5 and PM10 concentration	Facilitate transmission of SARS-CoV-2 virus droplets and particles in indoor environments (Amoateya et al., 2020)
		Italy (northern)	PM10 daily limit value exceedances	Significant increase in the number of cases (Setti et al., 2020)
		USA (California)	PM10	Significant Correlation (Bashira et al., 2020)
2	NO_2	66 regions of Germany, Italy France and Spain	highest NO_2 concentrations combined with downwards airflow	4443 total fatality cases, 3487 (78%) in north Italy and central Spain (Ogen, 2020)
		China (120 cities)	10 μg/m^3 increase in NO_2	6.94% increase in the daily counts of confirmed cases (Zhu et al., 2020)
		USA (California)	NO_2	Significant Correlation (Bashira et al., 2020)
3	SO_2	China (120 cities)	10 μg/m^3 increase in SO_2	7.79% decrease in the daily counts of confirmed cases (Zhu et al., 2020)
		USA (California)	SO_2	Significant Correlation (Bashira et al., 2020)
4	CO	China (120 cities)	1 μg/m^3 increase in CO	15.11% increase in the daily counts of confirmed cases (Zhu et al., 2020)
		USA (California)	CO	Significant Correlation (Bashira et al., 2020)
5	O_3	China (120 cities)	10 μg/m^3 increase in O_3	4.76% increase in the daily counts of confirmed cases (Zhu et al., 2020)

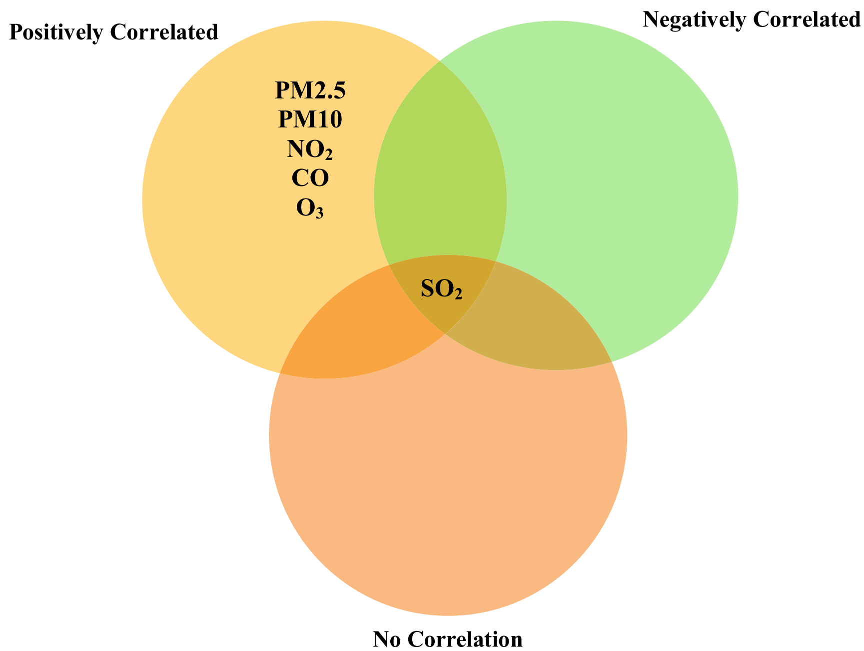

Fig. 1. Relationship between various pollution parameters with number of COVID19 cases.

4.1. Temperature and COVID19

In studies conducted to understand the relationship between temperature and COVID19 cases showed extremely unusual results. Relationships were mostly place and facility specific. A study was conducted in top 10 affected provinces of China showed asymmetric nexus between temperature and COVID-19. In five of the ten provinces three showed positive, two negative while remaining five showed mix trends between temperature and COVID19 cases (Shahzad et al., 2020). In another study conducted in New York a significant relationship was found between average and minimum temperature with COVID19 cases (Bashir et al., 2020). In yet another study carried out in Wuhan, China shows that contrary to many earlier studies which suggest a significant role of temperature in slowing down the COVID-19 spread. The results suggested no significance of an increase in temperature to contain or slow down the COVID-19 infections (Iqbal et al., 2020). In yet another study in Italy showed that an increase in the average daily temperature by 1 °F reduced the number of cases by approximately 6.4 per day. In some other cases COVID-19 mortality showed no significant association with temperature (Sobral et al., 2020; Ahmadi et al., 2020).

In another study conducted in 17 different cities of China yielded a result that 1 °C increase in Ambient Temperature and Diurnal Temperature Range was related to the decline of daily confirmed case counts (Liu et al., 2020). In one of the studies carried out in Turkey found that lower the temperature on a day, the higher is the number of COVID-19 cases on that day (Sahin, 2020). In a study in Jakarta (Indonesia) showed no correlation between temperature and number of cases observed (Tosepu et al., 2020). In one study done in China it was observed that temperature is an environmental driver of the COVID-19 outbreak in China. Lower and higher temperatures might be positive to decrease the COVID-19 incidence (Shi et al., 2020).

Table 2
Effect of various meteorological parameters on number of COVID19 cases and mortality.

S. No.	Parameter	Country	Relationship and Result
1	Temperature	China (10 affected provinces)	Asymmetric Nexus Between Temperature and COVID-19, few show positive, few negative and some mixed trend (Shahzad et al., 2020)
		USA (New York)	Increase in average and minimum temperature significantly lower number of COVID19 cases (Bashir et al., 2020)
		China (Wuhan)	No significance of an increase in temperature to contain or slow down the COVID-19 infections (Iqbal et al., 2020
		Italy	Increase in the average daily temperature by 1 °F reduced the number of cases by approximately 6.4 per day (Sobral et al., 2020)
		Iran	No significant relationship between temperature and COVID19 (Ahmadi et al., 2020)
		China (17 different cities)	1 °C increase in ambient temperature was related to the decline of daily confirmed case counts (Liu et al., 2020)
		Turkey	Lower the temperature on a day, the higher is the number of COVID-19 cases on that day (Sahin, 2020)
		Indonesia (Jakarta)	Temperature is significantly related to number of COVID19 cases (Tosepu et al., 2020)
		China	Lower and higher temperatures might be positive to decrease the COVID-19 incidence (Shi et al., 2020)
2	Humidity	USA (New York)	Average Humidity doesn't play much significant role in number of cases or total number of cases (Bashir et al., 2020)
		Iran	Humidity has a reverse relationship within the virus outbreak speed (Ahmadi et al., 2020)
		China (all provincial capitals)	Absolute humidity was significantly related, 1 g/m^3 increase in AH was significantly associated with reduced confirmed case (Liu et al., 2020).
		Turkey	An increase in humidity results in a decrease in number of cases (Sahin et al., 2020)
		China	No significant association between COVID-19 incidence and absolute humidity was observed (Shu et al., 2020)
		General	Air humidity is negatively correlated with COVID19 morbidity and mortality (Biktasheva, 2020; Martineza et al., 2020)
3	Rain Fall	USA	Rainfall is negatively and weakly correlated with spread of COVID19 (Bashir et al., 2020)
		Italy	Rainfall showed an increase in disease transmission. For each average inch/day, there was an increase of 56.01 cases/day (Sobral et al., 2020)
		Iran	No correlation between rainfall and number of COVID19 cases (Ahmadi et al., 2020)
		Indonesia (Jakarta)	Rainfall was not significantly correlated with COVID-19 (Tosepu et al., 2020
3	Wind speed	USA	Wind speed insignificantly play some role in the spread of the virus (Bashir et al., 2020)
		Iran	Outbreak at low speed of the wind is significant (Ahmadi et al., 2020)
		Turkey	Higher the wind speed is, more the number of cases is (Sahin et al., 2020)
5	Solar Radiation	Iran	Solar radiation threats the virus's survival. Areas with low values of solar radiation showed high rate of exposure to infection (Ahmadi et al., 2020)

4.2. Humidity and COVID19

Many studies across world have proved that humidity plays a crucial role in morbidity and mortality due to COVID19. In a study carried out in New York, it was observed that Average Humidity doesn't play much significant role in number of cases or total number of cases (Bashir et al., 2020). In Iran a study observed that humidity has a negative relationship within the virus outbreak speed, however, in two humid regions of Iran, the rate of virus spreading is high (Ahmadi et al., 2020). A study covering all the provincial capitals of China found that Absolute Humidity (AH) had significant negative effects on confirmed case counts for 4 cities. Meta-analysis showed that each 1 g/m^3 increase in AH was significantly associated with reduced confirmed case (Liu et al., 2020). In Turkey it was observed that the association between humidity and the number of cases is the most on the day of the case. The overall correlation was negative, which indicates that an increase in humidity results in a decrease in number of cases (Sahin et al., 2020). In yet another study done in China observed no significant association between COVID-19 incidence and absolute humidity (Shi et al., 2020). In an important study it was reported that areas with significant community transmission of COVID-19 had distribution roughly along the 30-50° N corridor (South Korea, Japan, Iran, and Northern Italy) through March 10, 2020 consisting of varying relative humidity (44–84%) but consistent low specific (3–6 g/kg) and absolute humidity (4–7 g/m^3) (Sajadi et al., 2020).

4.3. Rainfall and COVID19

Studies, although very less, have shown relation of COVID-19 with the rainfall. In a study done in the United States shows that rainfall is negatively and weakly correlated with spread of COVID-19 (Bashir et al., 2020). Countries with higher rainfall showed an increase in disease transmission. For each average inch per day of rainfall, there was about 56 cases/day increase (Sobral et al., 2020). In another study conducted in Iran finds no correlation between rainfall and number of COVID-19 cases (Ahmadi et al., 2020). Similarly in a study in Indonesia shows rainfall was not significantly correlated with COVID-19 (Tosepu et al., 2020).

4.4. Wind speed and COVID-19

In general wind speed does not seem to be a major role player and thus so far few studies have been done. In a study done in USA finds that wind speed insignificantly play some role in the spread of the virus (Bashir et al., 2020). While a study carried out in Iran observed that the outbreak at low speed of the wind is significant (Ahmadi et al., 2020). Interestingly a study conducted in Turkey revealed that the average wind speed in 14 days has the highest correlation with the number of cases. That is higher the wind speed is, more the number of cases is. The results indicated that the most reasonable time span is 14 days, meaning that the wind speed in 14 days of the cases should be considered for determining the right correlation (Sahin, 2020).

4.5. Solar radiation and COVID19

Extremely less number of studies have been done on association between COVID-19 and solar radiation. In a study done in Iran revealed that Solar radiation threats the virus's survival. Areas with low values of solar radiation showed high rate of exposure to infection (Ahmadi et al., 2020).

Relation between various meteorological parameters and number of COVID 19 are illustrated in Fig. 2.

5. Effect of COVID-19 (lockdown) on the air quality

Spread of COVID-19 resulted in lockdown across the countries of the world. Restricted movements due to lockdown caused emission of lesser amount of carbon or other pollutants into the atmosphere. This actually proved to be an unprecedented situation as far as pollution emission is concerned in many decades across the globe. Some prominent effects on air quality due to lockdown in context to some major criterion pollutants are provided in Table 3 and discussed in the preceding paragraph. The final results have been illustrated in Fig. 3.

5.1. Particulate matter

In one of the earliest (Jan to March 2020) studies carried out in China on the effect of lockdown revealed a reduction of 26–48% and 29–34% in the concentration of PM2.5 and PM10 respectively (Li et al., 2020). In another study in Milan conducted during the early phase of COVID19 outbreak and lockdown resulted into 26–48% and 13.1%–18.9% reduction in PM2.5 and PM10 respectively. Also a conspicuous reduction of 57–71% in the concentration of Black Carbon (BC) was observed (Collivignarelli et al., 2020). In yet another study done in Sao Paulo, Brazil, a significant reduction of up to 30 and 20%, depending on the site, was observed in the mean concentration of PM2.5 and PM10 respectively (Nakada and Urban, 2020). In an study conducted on PM2.5 concentrations over major cities around the world, a significant reduction between 11 and 58% was observed (Chauhan and Singh, 2020).

In the northern parts of India, a five year low in the stubble burning, which is responsible for the smog formation and drastic reduction in visibility, was observed (Hindustan Times May 2020). In another study in eastern part of India conducted on the variation of PM10 due stone quarrying industries a reduction of 73–78% in PM10 concentration during pre and post lock down period was observed (Mandal and Pal, 2020). In yet another study done in the 22 cities across India showed 43 and 31% reduction in PM2.5 and PM10 concentrations respectively (Sharma et al., 2020).

5.2. Oxides of nitrogen (NOx)

NOx one of the important criterion pollutants and a major health hazard was study in different countries across the world during lockdown. Interesting results were obtained most of them showed a significant decrease in the NOx concentration. In an early study in China 29–47% reduction in NOx concentrations was observed due to lockdown (Li et al., 2020). 47 ± 15% reduction in tropospheric NOx was observed in Milan due to lockdown (Collivignarelli et al., 2020). Up to 77.3% and 54.3% decrease in NO and NO_2 concentrations respectively were observed in Sao Paulo, Brazil due to lockdown (Nakada and Urban, 2020). In a study comprising 22 cities across India, noticed on an average 18% reduction in the NO_2 concentration (Mandal and Pal, 2020).

5.3. Other gaseous pollutants

Other important pollutant gases such as SO_2, CO, O_3, VOCs were also studied in different countries during lockdown. Significant variations were noticed. In one of the initial studies during lockdown carried out in China revealed 16–26%, 21–26% and 37–57% decrease in the concentration of SO_2, CO and VOCs respectively. However, an increase (healing) of O_3 by 20.5% was observed during the same period (Li et al., 2020). In a study carried out in Milan, Italy, 55–75%, 20–27%, 48–68% reduction in the concentration of CO, SO_2 and Benzene respectively was observed due to lockdown. Contrary to other pollutants, a significant increase of around 50% in the concentration of ozone was observed (Collivignarelli et al., 2020). Study carried out is Sao Paulo shows reduction of 18–33% and 36–65% in the concentration of SO_2 and CO respectively, but an increase of 30% in the ozone level was also observed due to the lockdown (Nakada and Urban, 2020).

In a study carried out across 22 cities of India reports a 10% decrease in CO concentration while no change was observed for SO_2 concentration. However O_3 concentrate was increased by 17% (Sharma et al., 2020).

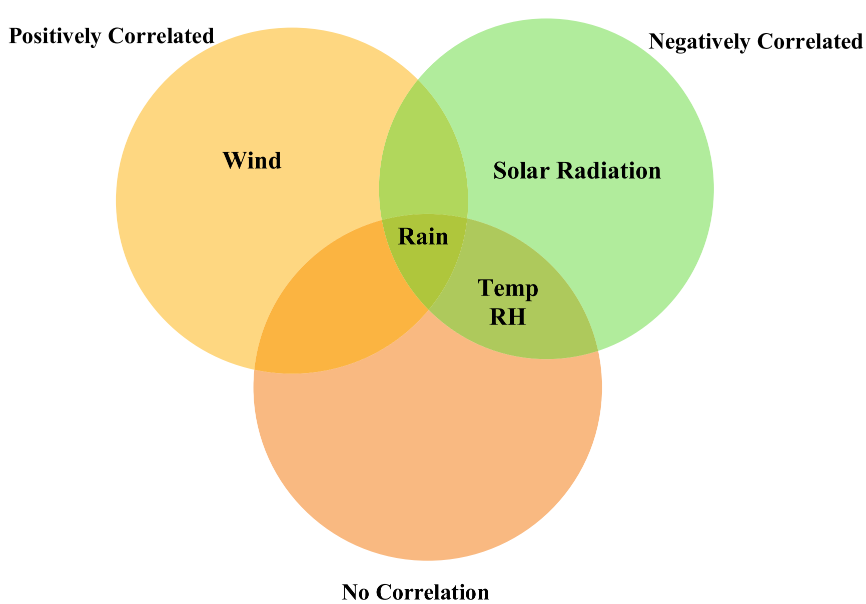

Fig. 2. Relationship between various meteorological parameters with number of COVID19 cases.

Table 3
Effect of lockdown due to COVID19 on various atmospheric pollutants.

S. No.	Parameter	Country	Effect
1	PM2.5	China	26–48% reduction (Li et al., 2020)
		Italy (Milan)	37.1–44.4% reduction (Collivignarelli et al., 2020)
		Brazil (Sao Paulo)	Up to 29.8% reduction (Nakada and Urban, 2020)
		Major city of World	11–58% reduction (Chauhan and Singh, 2020)
		India (22 cities)	43% reduction (Sharma et al., 2020)
		Southeast Asia	23–32% reduction (Kanniah et al., 2020)
2	PM10	China	29–34% reduction (Li et al., 2020)
		Italy (Milan)	13.1–18.9% reduction (Collivignarelli et al., 2020)
		Brazil (Sao Paulo)	Up to 22.8% reduction (Nakada and Urban, 2020)
		Estern India	73–78% (Mandal and Pal, 2020)
		India (22 cities)	31% reduction (Sharma et al., 2020)
		Southeast Asia	26–31% reduction (Kanniah et al., 2020)
3	Black Carbon	Italy (Milan)	57.5–71% reduction (Collivignarelli et al., 2020)
2	NOx	China	29–47% reduction (Li et al., 2020)
		Italy (Milan)	47 ± 15% reduction in tropospheric NOx (Collivignarelli et al., 2020)
		Brazil (Sao Paulo)	77.3% decrease in NO and 54.3% in NO_2 (Nakada and Urban, 2020)
		India (22 cities)	18% reduction (Sharma et al., 2020)
		Southeast Asia	63–64% reduction (Kanniah et al., 2020)
3	SO_2	China	16–26% reduction (Li et al., 2020)
		Italy (Milan)	20–27% reduction (Collivignarelli et al., 2020)
		Brazil (Sao Paulo)	18–33% reduction (Nakada and Urban, 2020)
		India (22 cities)	No change (Sharma et al., 2020)
		Southeast Asia	9–20% reduction (Kanniah et al., 2020)
4	CO	China	21–26% reduction (Li et al., 2020)
		Italy (Milan)	55–75% reduction (Collivignarelli et al., 2020)
		Brazil (Sao Paulo)	36–65% reduction (Nakada and Urban, 2020)
		India (22 cities)	10% reduction (Sharma et al., 2020)
		Southeast Asia	25–31% reduction (Kanniah et al., 2020)
5	VOC	China	37–57% reduction (Li et al., 2020)
		Italy (Milan)	48–68% reduction in benzene (Collivignarelli et al., 2020)
6	O_3	China	20.5% increase (Li et al., 2020)
		Italy (Milan)	50% increase (Collivignarelli et al., 2020)
		Brazil (Sao Paulo)	30% increase (Nakada and Urban, 2020)
		India (22 cities)	17% increase (Sharma et al., 2020)
7	AOD	Southeast Asia	Notable decrease (Kanniah et al., 2020)
		India	Significant reduction Gautam 2020; Patel 2020; Katpatal 2020)
		Indo-Gangetic Basin, India	20–60% reduction (Mishra, 2020)

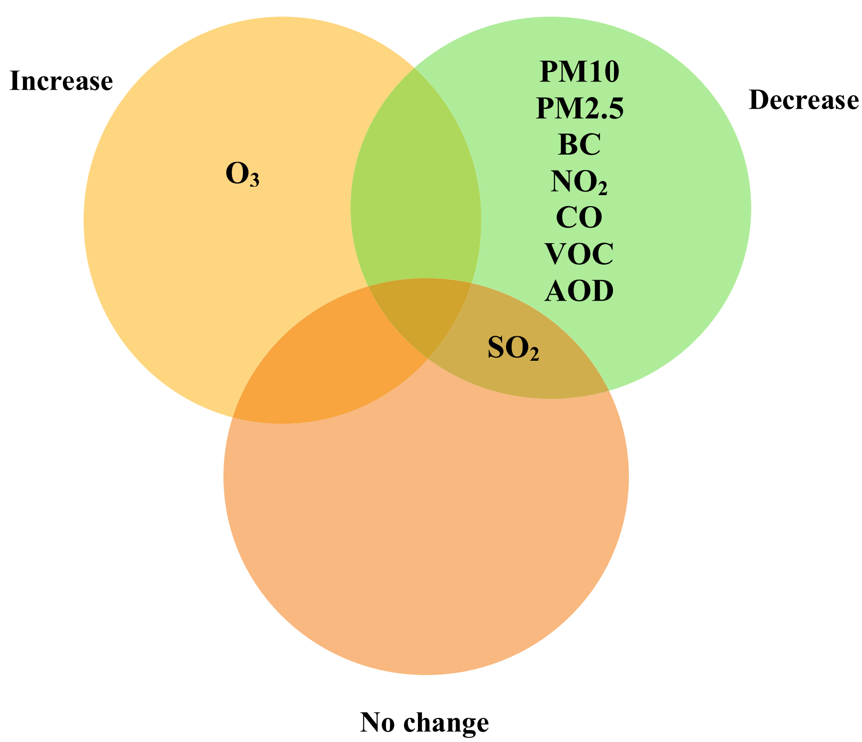

Fig. 3. Effect on various pollution parameters due to lockdown.

5.4. Aerosol Optical Depth (AOD)

AOD one of the important tools for monitoring and measuring particulate matters load in the atmosphere were also studied during lockdown. In studies carried out in Southeast Asia (Kanniah et al., 2020) and in India (Gautam, 2020; Patel, 2020; Katpatal, 2020) show a notable decrease in AOD values. In another study confined to Indo Gangetic Basin showed 20–60% reduction in AOD values (Mishra, 2020).

6. Conclusions

This study broadly finds out that SARS-CoV-2 viruses are most lethal in association with aerosols coming from sneezes, coughing and talking. It can survive for significant part of time and travel to some distance without losing its viability and virulence and thus pose threat. There is no evidence that viruses alone are airborne and also remains viable or virulent on particulate matters surface. However particulate samples are tested positive for SARS-CoV-2 gene markers. It has also been found that particulate matters and some other criterion gases pollutants are positively correlated with the number of COVID-19 cases and mortality caused by them. As far as local meteorology is concerned some of the parameters such as temperature and humidity are negatively correlated i.e. higher the temperature and humidity lesser the number of cases. Rainfall is nothing to do with number of cases while wind speed is positively related with the number of cases. Solar radiation poses a threat to the corona virus.

An effort was also made to find out the effect of lockdown on the air quality. Significant reduction in the concentration of PM10, PM2.5, BC, NOx, SO_2, CO and other gaseous pollutants were observed, more or less everywhere the monitoring was carried out. Noticeable decrease of upto 50% was observed in AOD one of the main precursors of air pollution specially particulate matters. Surprisingly O_3 concentration increased significantly and thus causing a healing effect in the ozone layer.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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