Techno-economic review on short-term anthropogenic emissions of air pollutants and particulate matter

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ABSTRACT

It is well known that pandemics not only change people's social habits but have also changed most activities related to energy consumption, especially industry and transport. Over the past year, a plethora of case studies have been published mapping the environmental impacts in specific locations in terms of changes in wastewater composition, noise, solar radiation and more. However, policymakers are demanding a global perspective and are looking for a synthesis of all these reports that will indicate whether, or to what extent, these changes interact with global climate change. The most urgent question is whether artificially inducing such a pandemic could be justified, given the loss of human life and economic losses. Robust analysis on air pollutants such as $PM_{2.5}$, PM_{10}, NOx, SO_2, CO, O_3 and NH_3 confirmed significant improvement in air quality indicators especially in India and China. The study indicates that key hypotheses can be confirmed or refuted, but further measurements are needed.

Keywords: Air quality, COVID-19, climate change, particulate matter, greenhouse gases

1. Introduction

The Global health systems involve various networks and organizations of various hierarchies to provide world-wide health improvement, reduction of disparities and protection against global threats that disregard national borders. The most eminent agency associated with the Global health is the World Health Organization (WHO) [**1**]. The Global health sector has successfully brought in various interventions and solutions for many infectious diseases around the world such as Zika, Chikungunya, Ebola, Nipah, Severe Acute Respiratory Syndrome (SARS), Middle East Respiratory Syndrome (MERS), and Influenza. Though it has brought in a stringent system to these diseases which has decreased the mortality rate and increased the life expectancy rate throughout the world, there are various sectors which are still a great challenge for the WHO. One of the very important challenges that involves preparing for Pandemics [**2**]. The emergence of the novel Corona virus at the end of 2019 has posted such a threat to the people worldwide, which started its transmission initially due to Human - Animal interface activities [**3**]. Corona Viruses include a large family of Viruses found in nature. It belongs to the Family ofCoronaviridae and order of Nidovirales possessing single stranded, positive-sense RNA genome. The technical name of corona virus is SARS-CoV-2. Corona Viruses are named for its crown like spike protruding from their surface. The Incubation period refers to the time between being exposed to the disease and when the actual symptoms start to show up. Knowing the incubation period of the disease is really helpful to take the necessary steps such as active monitoring, surveillance, control and modeling [**4**]. This time is critical for prevention of the diseases and allows the health officials to take decisions regarding quarantine or observe people who may have been exposed to virus. The novel coronavirus has an incubation period of 2 to 14 days, according to the CDC and with symptoms it appears about five days after the infection in most cases [**5**].Fatality rate refers to the proportion of deaths due to the disease when compared to the people who have been diagnosed with the same. The fatality rate shows the severity of the disease. The WHO has estimated the fatality rate of novel corona virus which is about 3%.R-Naught is a mathematical value which refers to the reproduction rate of the disease.

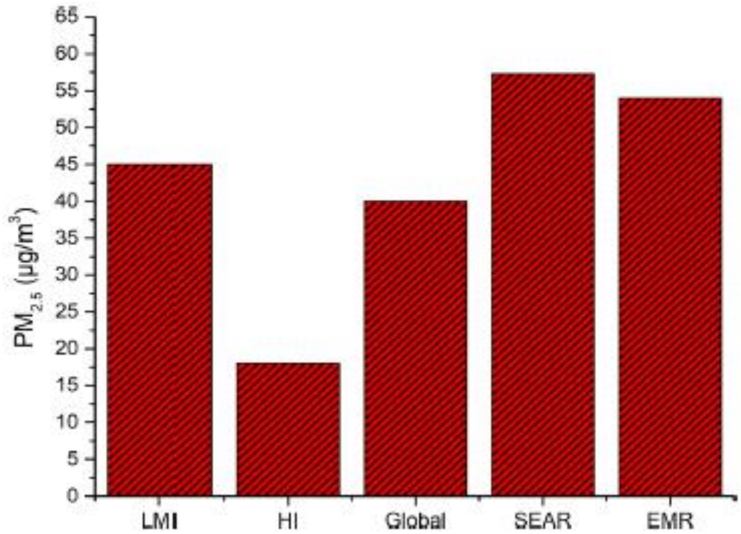

Fig. 1. Global distribution of $PM_{2.5}$.

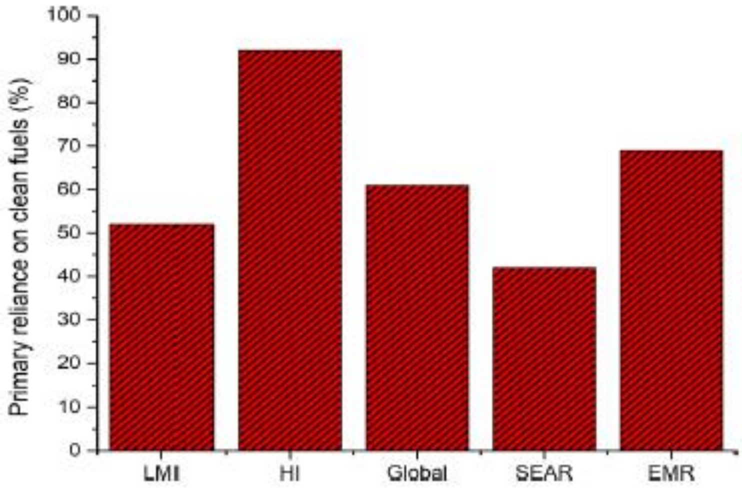

Fig. 2. Clean fuel global utilization.

R_0conveys how many persons will get infected because of one infected person in average [**6**]. This R_0 value applies only when a) no one has been vaccinated and b) no one has been immune to it yet. As such, there's no way to control the spread of the disease. Accordingly, the R-Naught of the novel Corona virus is predicted to be between 2 and 4, which means, an infected person may infect 2 to 4 healthy people [**7**].

Particulate matter emission in the rate of 2.5 µm or less affects the human body adversely by causing several disorders due to the quality of air they breathe. The PM is classified into two parts, such as primary and secondary. Primary is directly emitted to the atmosphere and the secondary is produced based on the physical and chemical reactions. $PM_{2.5}$ includes carbon (elemental and organic), metal sulphate (SO_4), nitrate (NO3), ammonia (NH4) and aerosols (SOA). As per the WHO health report 2019, 9 out of 10 people in the urban area are exposed to PM2.5 that is above the air quality index of 10 µg/m^3. Specifically, the highest mean level is reported in the East Asia Region and Eastern Mediterranean region of 57.3 µg/m3 and 54.0 µg/m^3 respectively. Despite the recent clean fuel technology, 3 billion people are exposed their health to high risk by cooking in the polluted fuels and technologies.

Due to the poor global air quality, 7 million deaths were reported in 2016 alone as per WHO. The major deaths were reported with stroke, heart diseases, cancer, chronic and respiratory issues. With regard to the mortality sex ratio, men are highly exposed compared to women. For illustration, the ratio of death of men and women was 128.5: 101.1 per 100,000 populations. The highest PM2.5 emission was reported in the South East Asia region (SEAR) (57.3 µg/m^3, Eastern Mediterranean region (EMR) (54.0 µg/m^3) and Region of America (13.4 µg/m^3). Further, when compared to the low and middle income (LMI), the high income (HI) was reported less emission of PM2.5 in 2016 stated by WHO [**46-49**]. The **Fig. 1** presented the detail of emission rate for the global and local regions. Due to the serious pollution and global warming rates, the WHO has taken several measurements and encouraged to utilize the clean fuels [**50-53**]. The growth of usage of clean fuels was increased by 12% (2000-2017). The lowest usage of the clean fuels was reported in the African region by 17% meanwhile the highest use of the clean fuels was reported by European region by 95% (**Fig. 2**) [**8,50,54**].

This review summarizes the effect of COVID-19 effects on global air quality. Due to this, the energy patterns have been changed enormously in a positive way which suits a common saying of "a blessing in disguise". This is the first time; the whole world has undergone a major pandemic lockdown, hence understanding the role of non-essential on-air pollution is obligatory to improvise the air quality in future by the introduction of remote technologies. Despite the limited studies on the COVID-19 impact on air quality, this review will fill the gap of that knowledge by analyzing the impact created by COVID-19 globally from January 2020 to June 2020. The main objective of the work is to analyze the air quality globally during the lockdown in the major affected cities throughout the world and compare them with 2018 and 2019 air quality. Further, the role of temperature and humidity on the transmission of COVID-19 was reviewed. The results of these findings will be extremely helpful to enforce the air pollution regulations in future.

2. AQI and health risk calculation

To understand the impact of air quality, the AQI was determined. The AQI was determined based on the 8 major pollutants $PM_{2.5}$, PM_{10}, NOx, SO_2, CO, O_3, Pb and NH_3. The concentration ranges were classified varied for every country based on their policies [**9,10**]. For instance, in India AQI scale range from 0 to 500. Based on the range the index the quality of the air was classified as good (0-50), satisfactory (51-100), moderate (101-200), poor (201-300), very poor (301-400), and severe (401-500) [**11**].

Sub index air quality index (AQI_i) given by

$$AQI_i = \frac{I_{HI} - I_{LO}}{BR_{HI} - BR_{LO}} *(C_i\_BR_{LO}) + I_{LO} \quad (1)$$

C_i – Concentration of pollutant 'i'; I_{HI} and I_{LO}- AQI index greater and smaller corresponding values; BR-Break point concentrations.

$$\text{Therelativeriskofpollutants}(RRi) = \exp(\beta_i(C_i - C_{min,i})) - 1, C_i > C_{min,i}$$

$$I_i = f(X_i), i = 1, 2\cdots..n(\text{nisthenumberpollutants}) \quad (3)$$

Overall index (I)

$$I = F(I_1, I_2, \cdots I_n) \quad (4)$$

$$\text{Sumofvaluesofeachpollutant}(RR - 1)_{Total} = \sum_i [RR_i - 1] \quad (5)$$

βiis represented as exposure-response relationship coefficient [**12**] Density of vapor or absolute humidity (ρ_v (g/m^3) [**5,13**]

$$\rho_v = 1000 * \frac{e}{R_v T} \quad (6)$$

Where e- vapour pressure; R_V gas constant for water vapour; T-Ambient temperature

3. Results and discussion

3.1.Concentration of air pollution in India

3.1.1. Outbreak of COVID-19 in India

The first case of the COV-2 was identified in Kerala, India with China origin at the end of January 2020. As per the world health organization's situation update as on 31th January 2020, the worldwide confirmed cases were 9720 with mortality rate of 2.1% but outside of China, only 106 confirmed cases were reported in 19 countries. Among these 19 countries, Japan and Thailand had 14 new cases in each country. As on that date, the corona virus is believed to be transmitted from person to person through droplets. According to the situation report-2 released on 6th February 2020, the confirmed cases were 3 without any death. However, the china reported 583 new deaths with 28,016 new cases. On the other hand, Japan and Singapore recorded a spike in the new cases without any reported death. Due to the raise in the new cases, the government of India issued a quarantine noticeto people who have a travel history from 15th January 2020 from China. Further, as a preventive measure, the e-Visa for the Chinese passport holders is suspended. As on 6th February 1108 flights with 121,000 passengers are screened. A month later, as per the report on 9th March 2020, India reported 44 confirmed cases with the total global cases were 109,577. Outside of China, there was a major spike of 2867 confirmed cases with 686 deaths. The Indian council of medical research (ICMR) and National Centre for Diseases Control (NCDC) are closely monitoring the transmission rate of India. WHO appreciated the ICMR for keeping the spread rate in India was under control upon the initial counter measures in 1,387,297,452 populations. Among the Indian states, Haryana and Uttar Pradesh reported large number of confirmed cases of 14 and 9 individuals respectively. To avoid the transmission, all states were in high alert with 52 laboratories for testing COVID-19. On 22nd March 2020, the number of the cases was reached to 360 with 7 deaths. This condition panicked the India and urged for a complete lockdown. The first lockdown had been forced from 25th March 2020 to 14 April 2020. Nearly all factories and the services had been suspended. The arrests were made for violating the rules of lockdown and quarantine [**14**]. Despite the lockdown, the new confirmed cases were taken its toll. In the month of April, the cluster of the cases were reported. On 12th April, the confirmed cases were 8447 with 237 deaths and 765 discharges. 21 days lockdown did not stop the transmission of COVID-19. As per ICMR, 179,374 samples were tested for early diagnosis [**15,16**]. Due to the uncontrolled nature of the situation India had to take the complete lockdown gain as phase two from 15th April 2020 to 3rd May 2020 with some conditional relaxation to the non-contaminated zones (green zone). Based on the confirmed cases, zones are classified as red, orange and green. The governments ease the functions to operate agricultural business, public works department and cargo vehicles to transport essentials. After two lockdowns, due to the economic crisis, the lockdown was completely lifted with few restrictions on red zone and orange zone. This triggered the reproduction rate of COVID-19 substantially. As on June 10, 2020 the total confirmed cases were 298,283 with total death of 11,128. This pushed the India to rank 4 among other countries in the world with high number of infection and United States of America was on the top position with 2,084,058 infected cases with 115,908 deaths as per the worldometers [**17**]. The ICMR tested 46, 66,386 samples of COV-2 as on 7th June 2020.Serious awareness has been created by the officials among public to wear mask and maintain the social distancing. Some technologies like drones have been used to monitor the people movements in the restricted area. However, until the vaccine is found it is very difficult to keep the CoV-2 under control in the high-density countries like India.

India is the second largest populous country in the world. Due to the rapid development of the industrialization and urbanization, the air pollution has increased in the last 10 years. India consists of 4,000 cities and about 300 cities with more than 1,00,000 population. The major cities of India are

Mumbai, Delhi, Bangalore, Hyderabad, Ahmedabad, Chennai and Kolkata. These major cities drive the economy of the India. On the other hand, the density of people residing in the city was too high to cause rise in pollution levels. Air pollution in India has been a major concern over the decades, about one million people has been died due to the PM pollution [**18**]. Thus, controlling them is crucial before the conditions are worsening. Compared to other cities, the situation in the national capital Delhi is alarming. For instance, the concentration of the $PM_{2.5}$ in Delhi is 10 times higher than the Washington DC as per WHO [**18**]. Recent study concluded that reducing the $PM_{2.5}$ intensity to the prescribed levels can save 41 out of 100 thousand lives in Delhi alone [**19**]. To a make a detailed study on the change of air quality during the lockdown period, Shubham Sharma et al, collected the data from 22 cities covering the major part of the India including the major cities such as Mumbai, Bangalore, Delhi and Chennai. The data was obtained from the pollution board of India which is available as the open sourcehttps://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing[**20**] and **https://aqicn.org** [**21**].

3.1.2. Effect of air quality in India during COVID-19 outbreak

The concentrations are expressed as pollutant mass per unit volume of the atmospheric air and it is expressed in |rg/m3. Sensitivity of the air is monitored by the changes in ambient air pollution concentrations. All measurement of the data was only focused on the lockdown period of India from 15thMarch to 30th May 2020.

Shubham Sharma et al, measured the temporal change in the concentrations of the pollutants based on the six pollutants such as $PM_{2.5}$, PM_{10}, CO, and $NO_2$for five regions during the period of March 15th to April 14th 2020 and the obtained values were compared with data of 2017, 2018 and 2019 respectively. From the series of analysis, the pollutants$PM_{2.5}$, PM_{10}, CO, and NO_2reported 43%, 31%, 10% and 18% decrease in the concentration compared to the previous year's owing to the major lockdown. Further, 17% increase in O_3 was observed. On the contrary, the change in SO_2 was negligible. Besides, the reduction in the $PM_{2.5}$ was higher than PM_{10} which was due to the reduction of ultra-fine and fine anthropogenic particles presence in the atmosphere owing to the shutdown of factories and other major services. However the reduction of coarse particles was not observed significantly compared to $PM_{2.5}$ [**22**]. Contrarily, the north parts of the India reported drastic reduction in the concentration of pollutant. The average decrease in the concentration when compared to the previous years was 22% during the lockdown. Nevertheless, no reduction in SO_2 concentration was observed due to the continuous operations of coal power plants for the production of electricity. Similar to northern part of India, east India also reported the drastic reduction in the CO concentration. Furthermore, the concentration of O_3 was impressive, 77% and 89% higher compared to 2019 and 2017.SusantaMahato et al., analyzed the most populated city Delhi, India based on the seven pollutants parameters, $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, O_3 and NH_3. The data was obtained from the 34 monitoring stations by National Air Quality Index (NAQI) to study the influence of air quality due to COVID-19 lockdown [**23**]. The AQI data was measured between pre lockdown and during lockdown (3rd March 2020 to 14th April). Due to the implementation of lockdown, the $PM_{2.5}$ and PM_{10}were reduced by 53.11% and 51.84% respectively. With regard to NO_2, CO, NH_3 and SO_2, the reduction rates were 52.68%, 30.35%, 12.33% and17.97% respectively. Besides, there was a rapid increase in O_3 reported in the industrial and busy streets due to less emission of nitrogen oxides during lockdown than conventional period. Sneha Gautam observed the effect of COVID-19 on air quality. The study was made based on the image published by National Aeronautics and Space Administration (NASA) space observatory and European space agency (ESA) from Sentinel-5P. The images released by ESA were compared to show the effect of air pollution based on the pollutants NO_2. Based on the analysis there was a drastic decrease in the concentration of NO_2 which is the positive effect of the lockdown in the world environment despite the pandemic.

To be precise, the spatial pattern of National air quality index (NAQI) was obtained to compare the pre and during lockdown period. The NAQI was improved by 54% in the central part of Delhi on 21st march compared to 3rd March. This is the significant impact within the short span of time. Further, the other part of Delhi such as Eastern, Southern, Western and Northern also reported 49%, 43%, 37% and 31% reduction in NAQI. Similar to the above, the spatial mapping was done for all the major pollutants [**23**].

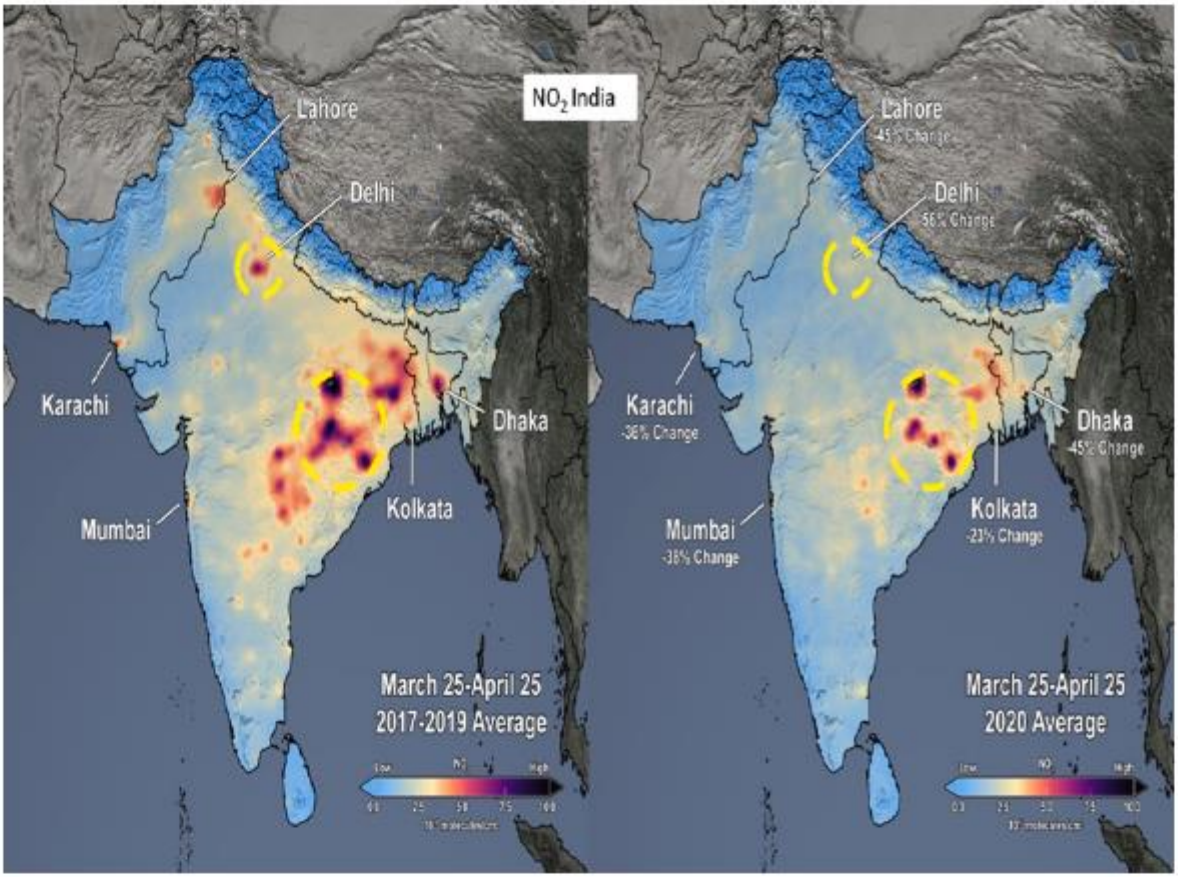

Fig. 3. Impact of NO_2 concentration over India [**23**].

All the data showed the significant reduction of pollution including NOx and SO_2 concentration. **Fig. 3** shows the effect of spatial NO_2concentration. From the Sentinel-5 Precursor it is very clear that the impact of the AQI was profound in India [**24**].

3.2. Concentration of air pollution in China

<u>*3.2.1. Outbreak of COVID-19 in China*</u>

As per the WHO situation report, on 31st December 2019, the unknown pneumonia virus was reported in Wuhan, Hubei. On 12thJanuary 2020, the origin of the novel Corona virus had been found. As per the report, the origin of the virus was from seafood market in Wuhan city. The first case outside of China reported by Thailand (2 cases), Japan (1 case) and Republic of Korea (1 case) on 20th Jan 2020. This was the first transport of CoV-2 outside China. Approximately 282 (258 Hubei, 14 Guangdong, 5 Beijing, 1 Shanghai, 1 Japan, 2 Republic of Korea, and 2 Thailand) cases were reported on 20th Jan 2020. After

4 days, there was a sharp increase in the confirmed cases to 830, which brought the Wuhan to lockdown. Followed by the transmission on 27th January 2020, the cases reached 2741 and the outside china cases increased to 37 in 11 countries. Social distancing was advised to limit human to human transmission since SARS transmit through droplets. In Hubei province the lockdown was followed until 8th April 2020 from 23rd of January. During the transmission period many foreign nations were sent to their respective countries as safety measures. Approximately 68 million people were quarantined in Wuhan and in other cities during the lockdown timeline. On 20th February 2020, the Chinese government took shutdownto all non-essential factories as part of countermeasures. Totally 68,128 confirmed cases with 4,512 deaths reported in Hubei province. From 13th March, the lockdown was brought to the noncontaminated areas such as Huangshi and Qianjiang. On 8th April, Wuhan lifted its lockdown to resume its routine life. From the above analysis it is evident that the strict lockdown was enforced on 20th February to 13th March in Wuhan.

3.2.2. Effect of air quality in China during COVID-19 outbreak

To control the transmission of the CoV-2, China implemented the complete lockdown in Hubei province. On 23rd January 2020, the China enforced self-quarantine measures and restricted the movement of the people. Two days after that, all parts of China brought to complete lockdown with some restrictions. Due to this restriction majority of the industry stopped their regular working schedule. In addition, due to the ban of transport, the vehicle emission rates were taken a massive reduction. Approximately 780 million of people were suffered from various forms of travel ban and restriction during the initial period of transmission [**25**]. China is the highest populated country in the world, thus studying the role of China in global pollution plays immense role. However, the analysis of the emission data due to the COVID-19 is complicated due to the Chinese New Year holidays from 24th Jan 2020 to 2nd Feb 2020. During the holiday period, the transmission of the COVID-19 was severe which led to the lockdown of borders and cities. Compared to other cities of China, Wuhan and Nanjing had undergone strict lockdown rules. Chen et al., studied the declination in the air pollution rate due to the COVID-19 outbreak. Further, they had examined the mortality benefit amidst of lockdown [**26**]. Due to the lockdown and the improved air quality, the non-COVID-19 deaths were potentially decreased. The improved health benefits was commonly observed regarding to cardiovascular disease. The emission data for China obtained from open source (**http://www.mee.gov.cn/hjzl/ and https://aqicn.org**) [**21,27**]. **Fig. 4** represents the effect the air pollution in the major cities and the entire china province during the studied period [**28-30**].

Guojun et al., presented the initial assessment on the impact of the CoV-2 on air pollution for the China region during and after Chinese New Year. The AQI and PM were observed. The change in the AQI and the $PM_{2.5}$ was observed between 20 and 40 days before and after China spring festival [**31**]. Implementation of the lockdown improved the air quality. Compared to 2019 post China spring festival, at 2020 the overall AQI showed some reduction in the air pollution. Besides, it was observed that 18% and 17% reduction in the AQI and $PM_{2.5}$ in the lock down cities. The AQI and $PM_{2.5}$ had seen 19.4 points and 13.9 μg/m^3 decline compared to pre-lockdown. Further, the total reduction in $PM_{2.5}$ was 22.3 μg/m^3 compared to the previous year. Qiang wang et al. the emission data were observed before and after spring festival, 2020. There was a major impact in the climate as per National Aeronautics and Space Administration (NASA) research release by TROPOMI (Sentinel-5 Precursor). On comparing the previous year data, the concentration of the NO_2 dropped suddenly; this was not because of the change in climate or Chinese holidays. The massive reduction is purely due to the restriction of industries and people movement.

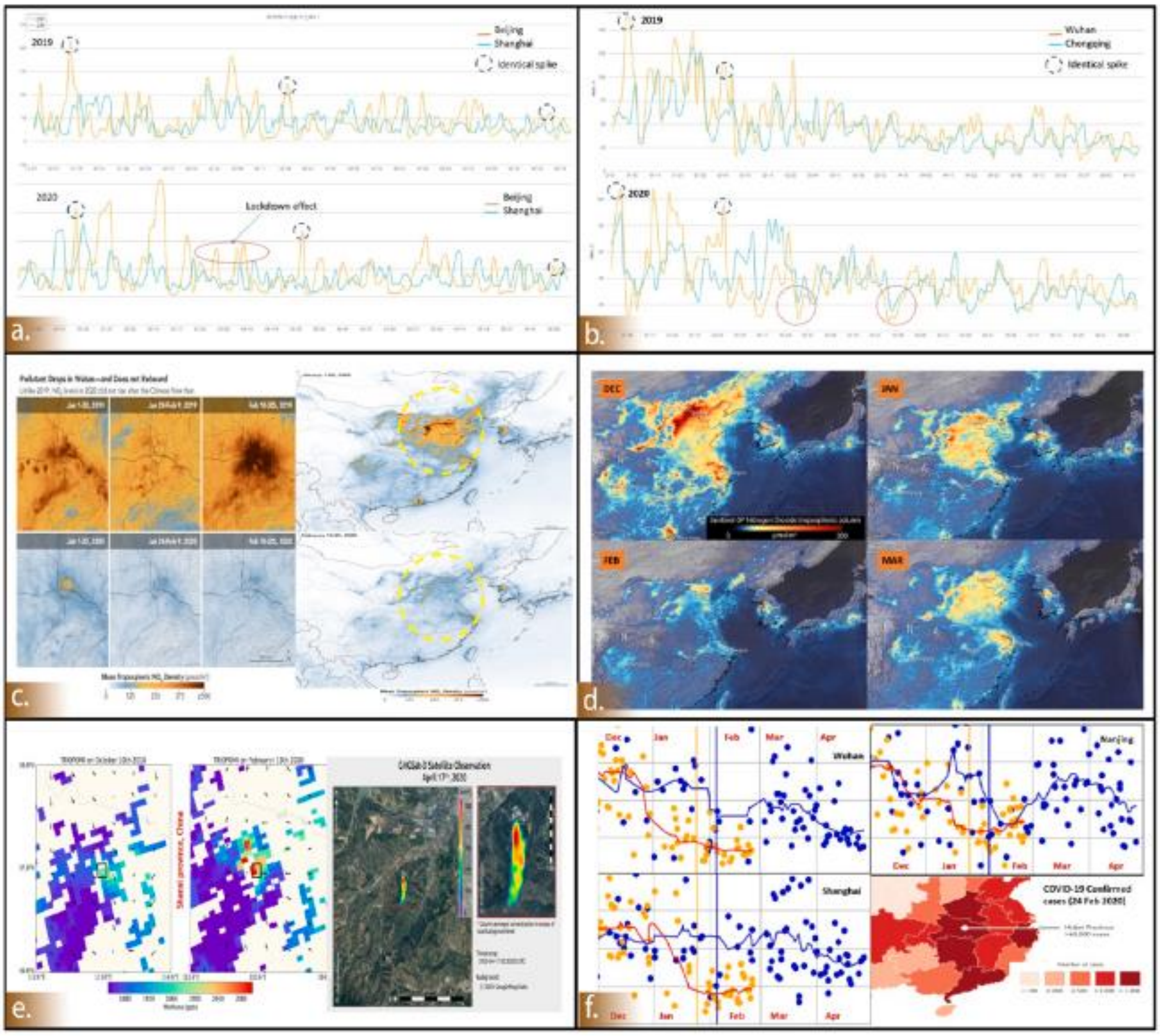

Fig. 4. a) Concentration of $PM_{2.5}$ Beijing and Shanghai b) Concentration of $PM_{2.5}$ Wuhan and Chongqing c) NO_2 concentration [**28**] d) NO2 Concentration in Beijing and Wuhan e) Effect of lockdown on AQI China [**45**] f) Methane concentration over Shanxi province [**27**].

Due to the covid-19 the energy consumption pattern of the China saw a sharp decline. Furthermore, the removal of the lockdown impacted the air quality worst due to the sudden spike in the movement of people and extensive operations of the industries [**25**]. Bauwens et al. observed the decline in NO_2 pollution rate in the course of COVID-19 using TROPOspheric Monitoring Instrument (TROPOMI) and Ozone Monitoring Instrument (OMI). Based on the spatial images released by Sentinel-5P, the comparison was done for China, Western Europe, United States and South Korea in the timeline of January 2020 to April 2020. The NO_2 observations during the lockdown were tabulated from TROPOMI and OMI [**32**]. From the results, it is evident that the change in levels of NO_2 is very high compared to the previous year and the pre-lockdown timeline. Every year there is a drastic reduction in the emission during the festival holidays. But this time, the emission continued to follow the same pattern as seen during the Chinese New Year, which clearly emphasizes the substantial decrease in the industrial activity. Further, 80% of the traffic was dropped during COVID-19 spread. Moreover, the traffic started to rise at the beginning of the March after lifting the lockdown in the noncontaminated zones.

The interesting study proposed by Yongjian Zhu et al, exposed the association between the COVID-19 infection and the air pollution. Several data were presented to confirm the positive association of the

COVID confirmed cases with respect to the pollutants $PM_{2.5}$, PM_{10}, CO, NO_2 and O_3. The Generalized additive model was applied for making the eventual comparison. A 10 µg/m^3 increase in pollutants $PM_{2.5}$, PM_{10}, NO_2, and O_3 was linked with a 2.24%, 1.76%, 6.94% and 4.76% increase in the daily counts of confirmed cases respectively [**33**]. On the contrary, SO_2 decreased the COVID-19 new confirmed cases. The study was done to predict the transmission of disease through concentration of pollutants. The Air pollution data was obtained in the open-source online platform (**https://www.aqistudy.cn/**). From the results it is evident that the CVOID-19risk factor is higher in the highly polluted areas. This means, the government should have given the priority to the polluted area compared to non- polluted province. Further, reducing the air pollution may help to combat COVID-19 infection. To be precise, exposure of the pollutants increases the possibility of COVID-19 infection and risk of respiratory disease. Another crucial study detected the effects of the temperature, diurnal temperature range (DTR) and humidity compared to COVID-19 mortality rate in China. From accessing the death count and the environmental data, the DTR was directly related to the increase in the mortality due to COVID-19 [**5**]. The relative and absolute humidity increased the recovery rate of the COVID-19 by reducing the mortality rate. DTR was slightly related with the increase in the death rates. Nevertheless DTR was associated with respiratory and cardiovascular diseases [**34,35**]. On the contrary, the humidity and temperature decreases the COVID-19 which is controlled by managing the pollution rate. Decrease of 1 unit of temperature and humidity decrease the mortality rate by 7.50% and 11.41%. Like SARS-CoV-2, CoV-3 is sensitive to the temperature, thus role of temperature and humidity is crucial to reduce the COVID-19 mortality rates [**26,36**].

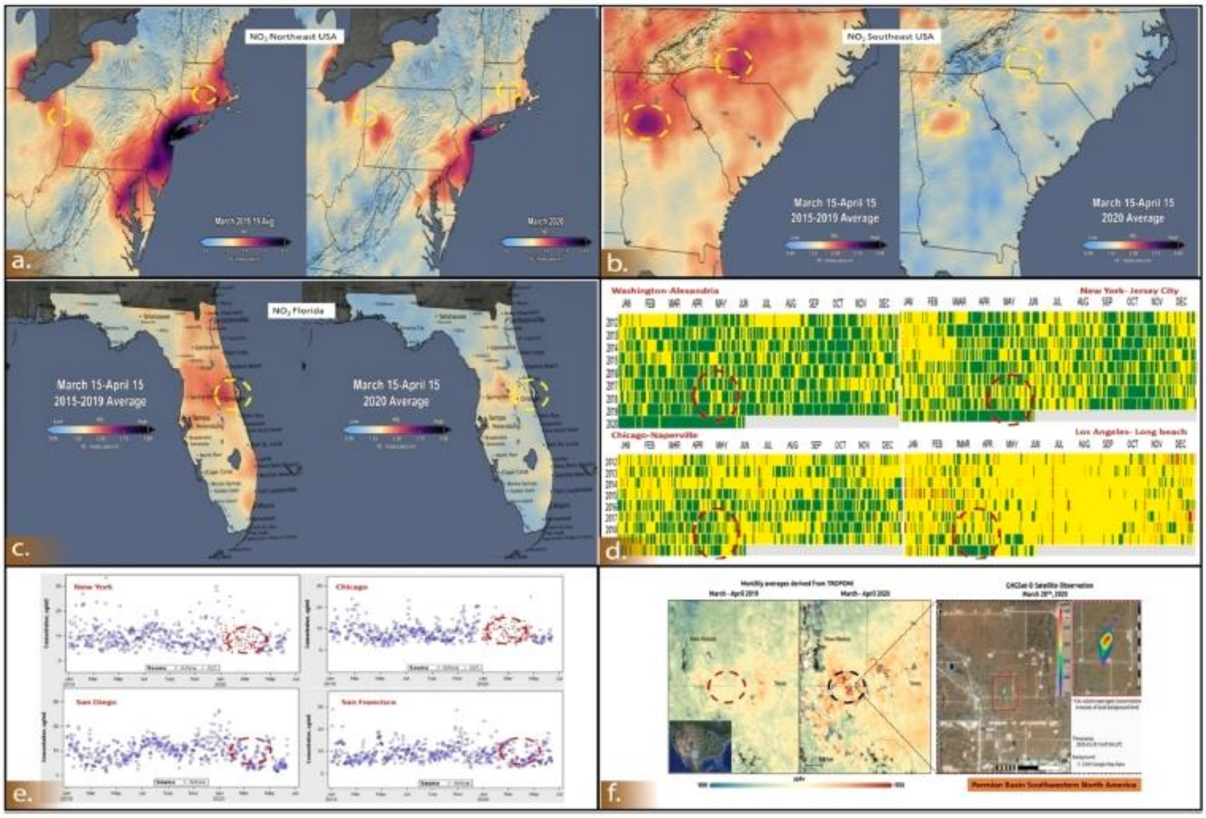

Fig. 5. a) NO_2 concentration north east USA b)NO_2 concentration south east USA Impact of AQI (2012-2020) f) Concentration plot for $PM_{2.5}$ for major cities.

3.3. Concentration of air pollution in USA

3.3.1. Outbreak of COVID-19 in USA

The first case of COVID-19 was reported on 19th January 2020 in Washington with history of Wuhan travel. Further, the first local transmission was recorded on Jan 30, who did not have travel history. This was the first case of local transmission reported in the Illinois, USA [**37**]. At end of March, the cases were confirmed in all 50 U.S. States. As on June 15, the number of confirmed cases was more than 2,162,228 with 117,858 deaths. Compared to the other infected countries, the death rate is 12% which is 2% higher than global cumulative fatality rate. This makes the USA as the worst epidemic center for COVID-19. Despite the massive government measure by achieving 23,290,724 tested samples the COVID-19 mortality and the total confirmed cases were high. New York and New Jersey were the worst hit centers in USA by clocking 30,911 and 12,733 deaths. In the earlier period of February, the government took several measures to stop the transmission of disease. The public health emergency was declared on 2nd February. Despite the countermeasures, the transmission was fast due to the manufacturing defects in the testing kits. The national emergency was declared on 13th March 2020 (1264 confirmed cases with 277 death) as the Centers for Disease Control and Prevention (CDC) predicted the huge wave of transmission. The travel restrictions were imposed and the people travel history from the contaminated areas came under scanner. By April 11, the total confirmed cases took a huge spike to 425,889 confirmed cases with 14,665 deaths which led to the launch of disaster declaration to all states of USA by federal government. As a result of this, the gatherings, events and schools were closed. Moreover, stays at home orders were issued. As on 15th June, it was 20,000 confirmed cases with 331 new deaths.

3.3.2. Effect of air quality in USA during COVID-19

In the United States of America, the fist COVID-19 was reported on 15th January 2020, and the transmission is very serious specifically in the city of New York, Florida and New Jersey. From the first week of April, all states of America came into lockdown except American Samoa, this changed the energy consumption patterns of the USA in large scale. The lockdown pattern in the USA is different from India since the lockdown was decided by the state governors. For instance, in Alabama the lockdown was enacted on 4th April and lifted on 30th April and Florida enacted the lockdown on 4th April and lifted on 4th May. So studying the cumulative air quality for the entire USA is slightly complex. The air pollution data was obtained from **https://www.epa.gov/o utdoor-air-quality-data** [**38**].

Bashir et al., assessed the correlation between the climate and COVID-19 pandemic in the New York city. The relation and the effect of COVID-19 on change in the atmospheric temperature was observed. New York is an ideal epidemic center for infectious disease due to its dense population. Like Wuhan, New York also showed a similar pattern in the COVID-19 transmission due to change in the temperature, air quality and the humidity [**39**]. The parameters such as average temperature, minimum temperature and the maximum temperature are correlated to the COVID-19. By controlling the air quality, the temperature can be altered significantly to combat COVID-19. From the Kendall correlation, Spearman correlation coefficient and the effect of temperature, new cases and mortality were observed. At the high temperature, the record of new cases and mortality was lower than the cases at average and low temperature. Another notable work predicted the effect of PM concentration on COVID-19 mortality. The mortality rate from the 3000 counties were collected until 22nd April 2020 and compared with the exposure of $PM_{2.5}$. From the analysis, they have observed the effect of change in mortality associated with the increase in $PM_{2.5}$. One unit increase in $PM_{2.5}$ leads to 8% increased death rate. Despite the marginal increase in $PM_{2.5}$, the death rates were predominating. Which is eventually proved by the Sentinel 5-P images [**40**] as represented in **Fig. 5**.

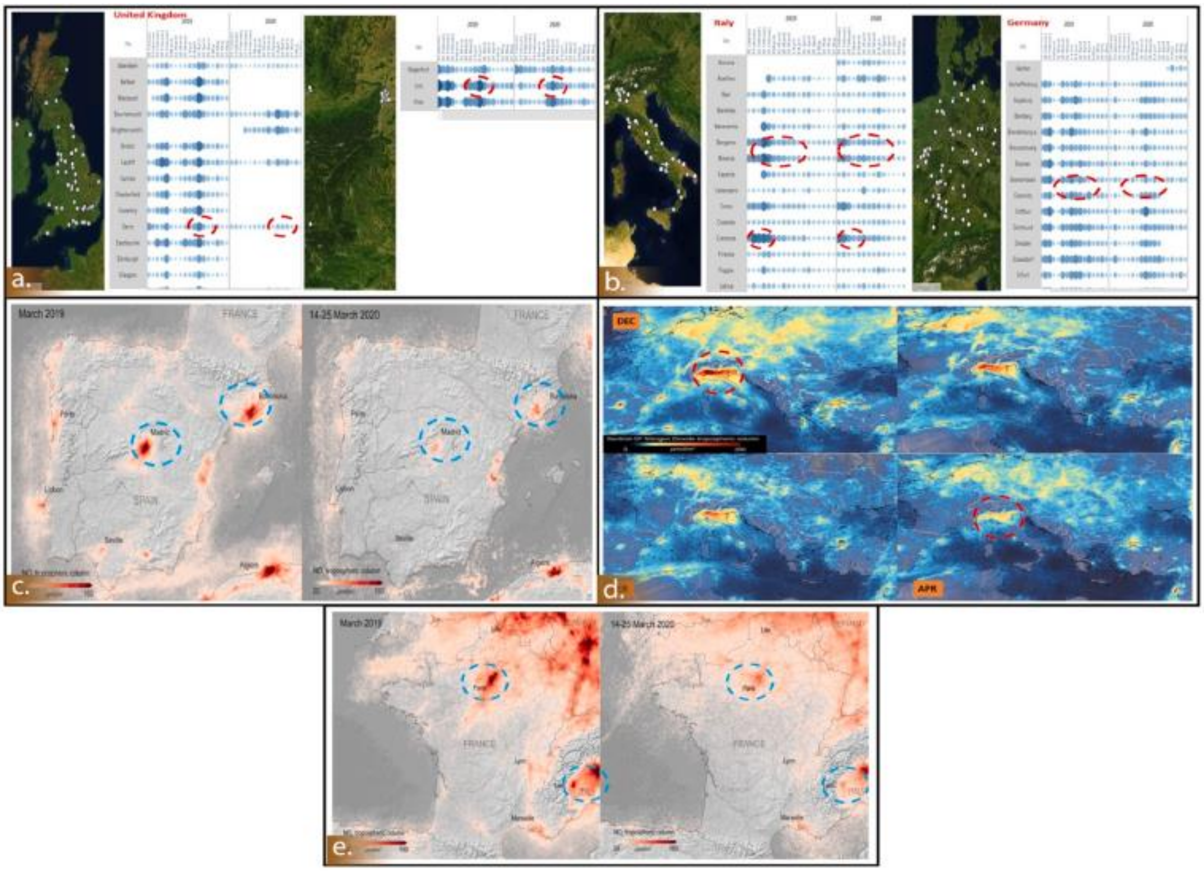

Fig. 6. a) $PM_{2.5}$ concentration United Kingdom b) $PM_{2.5}$ concentration Italy and Germany c) NO_2 concentration Italy and Spain d) NO_2 spatial distribution Italy [**46**] e) NO_2 concentration over France [**46**].

Table 1 Concentration of Pollutants from major study during COVID-19.

Study Period	Location	PM2.5	PM10	CO	NO_2	O3	SO_2	References
15th March – 14th April	India	−43	−31	−10	−18	+17		[11]
3rd March- 14th April	India	−53.11	−51.84	−30.35	−52.68	+0.78	−17.97	[22]
22nd January- April 04	Wuhan	−20			−21.7			[25]
	Hubei	−18.5			−16.9			
	Outside Hubei	−26.3			−15.6			
	China	−26			−15.7			
22 January - March 24	China	−22.3	−22.22		−4.7	+3.1		[30]
Year on change (First quarter 2020)	China	−14.8	−20.5	−6.2	−25		−21.4	[24]
February-March (21 days) TROPOMI* OMI	Beijing				−25*33			
	Shanghai				−11*29			
	Wuhan				−43*57			
	Venice				−33*33			
	Paris				−28*28			
	New York				−28*31			
	Washington				−21*21			
10th January to 10th April 2020	Milan	−32		−67.5	−47		−51.6	[42]
	Other parts(Sub area)	−38		−61.5			−85.1	

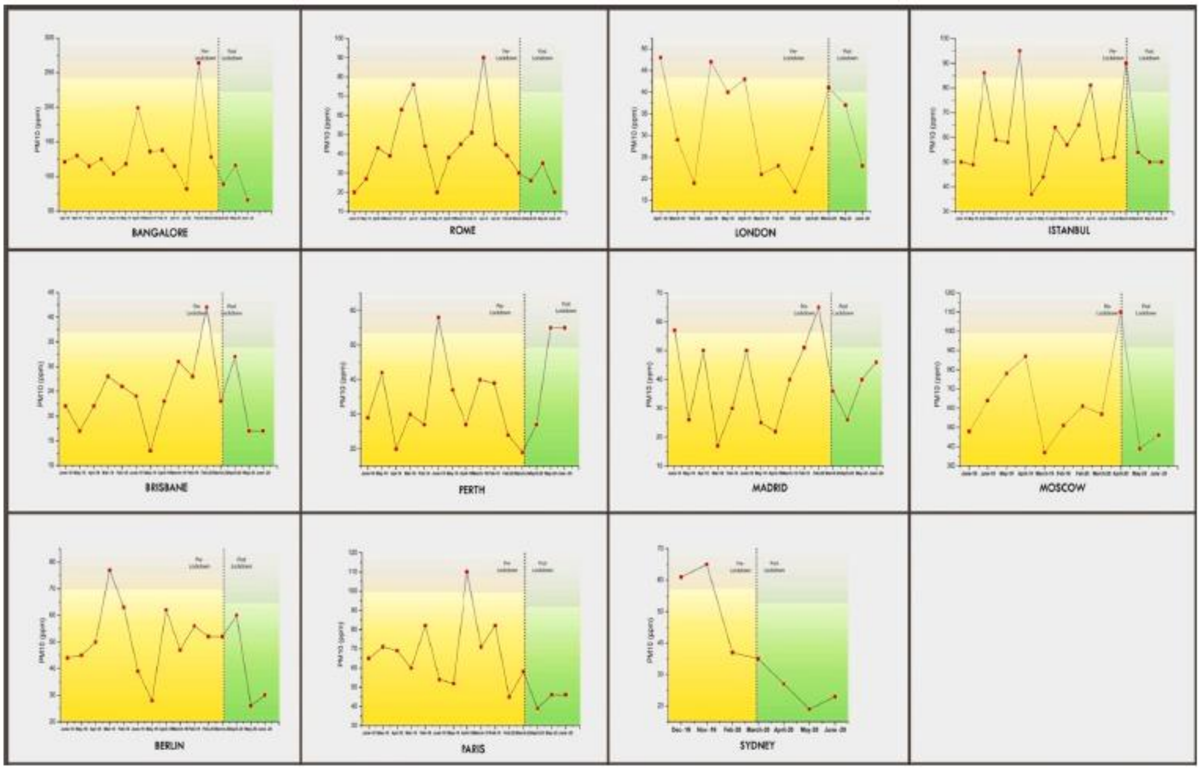

Fig. 7. COVID-19 impact on $PM_{2.5}$ concentration (2018–2020).

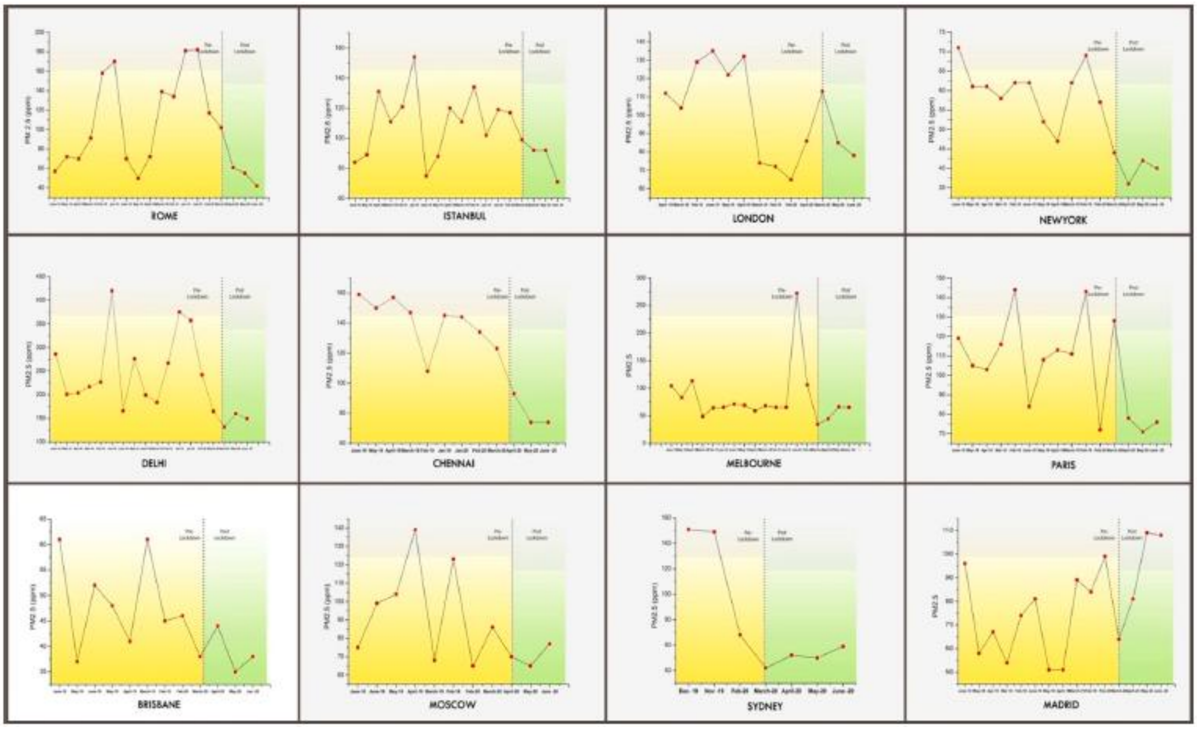

Fig. 8. COVID-19 impact on NOx concentration (2018-2020).

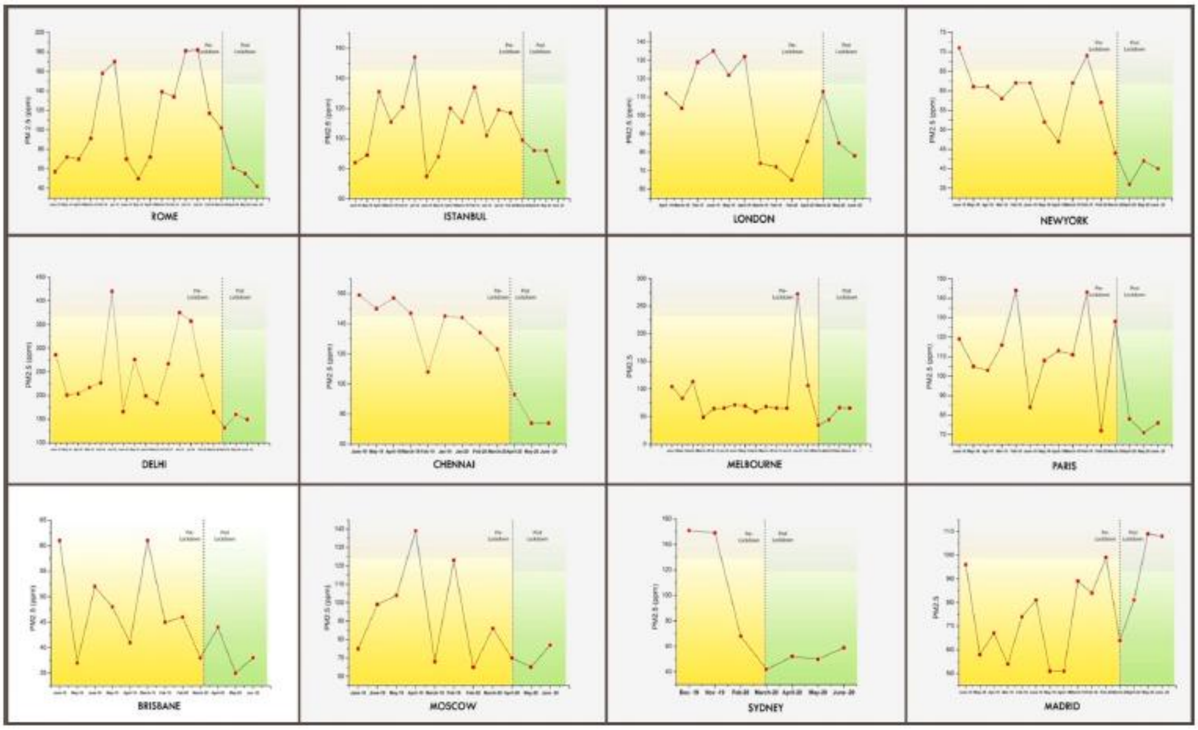

Fig. 9. COVID-19 impact on PM_{10} concentration (2018-2020).

3.4. Concentration of air pollution in Italy

3.4.1. Outbreak of COVID-19 in Italy

The impact of COVID-19 in Italy is very serious. It's ranked the 4th place in the total deaths as on April 16, with 237,290 confirmed cases. The first death of the Italy due to COVID-19 was reported on 21st February. Italy has reported a hasty increase in new cases COVID-19 since February 21. The Italian officials locked down the schools, coffee shops and public building in the northern Italy for reporting local transmission. Initially several clusters of cases were found in the northern Italy due to the local transmission. Initial phase of the lockdown began on 21st February 2020 in the providence of Lodi and Padua. On February24, total confirmed cases in Italy were 124 with two deaths. After a week there was a major increase in the confirmed case to 1128 with reported death of 29. As the infection continued to increase on March 9, the lockdown was expanded by covering sixteen million people. The officials banned travel, funerals, cultural events, restaurants, church and supermarkets to prevent onward transmission from 9th March to 18th May 2020. Besides, the strict lockdown was enforced on 23rd March to 3rd May 2020 by shutdown of all non-essential business and industries.

3.4.2. Effect of air quality in Italy during COVID-19

Greenhouse gas emissions have plummeted in Italy in recent years. 70% of the NO_2 emissions produced by the Italy are generated by transportation sector according to European Commission's Joint Research Center (ECJRC) as per latest report. Lockdown due to COVID-19 decreases the energy consumption rate which leads to a change in the quality of air we breathe. **Fig. 6** presented the observed change in air quality by different studies during the lockdown period. A notable study attempted to observe the effect of the atmospheric pollution on the COVID-19. The study related the pollution and the development of the respiratory diseases. High level of pollutant exposure causes higher chronic disorders. The positive relation between the fatality rate and the pollution in the Italian regions may be possible. This crucial study aggregated the relation between atmosphere pollution and the COVID-19 [**41**]. To predict the influence of air quality and the COVID-19 in Italian regions, the special correlation had been made. The association between the COVID-19 cases and the pollutants $PM_{2.5}$, PM_{10}, NO_2 and O_3were observed till 27th April 2020 [**42**]. Further, 71 Italy provinces data were compared to estimate the exposure of the atmospheric conditions and the infection [**38**]. They have reported the positive effect of change in PM and new confirmed COVID-19 cases. Thus, the role of the atmosphere pollution to combat the infectious diseases is vital. Collivignarelli et al., analyzed the air quality during the lockdown period in the city of Italy, Milan. The pollutants such as $PM_{2.5}$, PM_{10}, CO, NOx and benzene were taken for the analysis during the lockdown period. Further, the increase in O3 levels were monitored [**43**]. In Milan, the complete lockdown was enforced in the middle of the March. However, the industrial activity was not stopped until the last week of March. The depicted study monitored the air quality from 9th March to 5th April 2020 in the Milan city center and other sub areas. Due to the enforced lockdown, the concentration of SO_2 was reduced in Milan. Besides, there was no drastic reduction in the sub areas. With regard to the $PM_{2.5}$, PM_{10}, CO, benzene and NOx, there was a sharp decline in the pollutant concentration especially in the Milan city compared to other sub areas. This is mainly because of the reduced vehicular emission rate. On the other hand, the O_3 production rate was increased due to reduction of NOx.

3.5. Concentration of air pollution in Brazil

3.5.1. Outbreak of COVID-19 in Brazil

The first COVID-19 case of the Brazil was reported on 25th February 2020 in Sao Paulo which was imported from Italy. On March 16, the public health emergency was declared in Rio de Janeiro state. The school, public gatherings, cinema halls and other public events were cancelled. urther, the work at home was encouraged to stop the transmission. On 17 March, the first death was reported with 291 confirmed cases. The first lockdown was enforced from 24 March to 7 April and it was extended due to the uncontrolled pandemic. To stop the local transmission of the COVID-19, the travel ban was announced by the government officials on 27th March. As on June 2020, Brazil has the second highest number of confirmed cases behind USA. Despite the spike in COVID-19 cases, the lockdown was lifted in the major cities like Rio de Janeiro and Sao Paulo to resume their business. On June 17, 2020 the Brazil recorded a sudden rise in a single day by reporting 34, 918 confirmed cases. As on that day, the total confirmed cases were 928,834 with 45,456 deaths. However, the mortality rate was 9% which is less than Italy and USA.

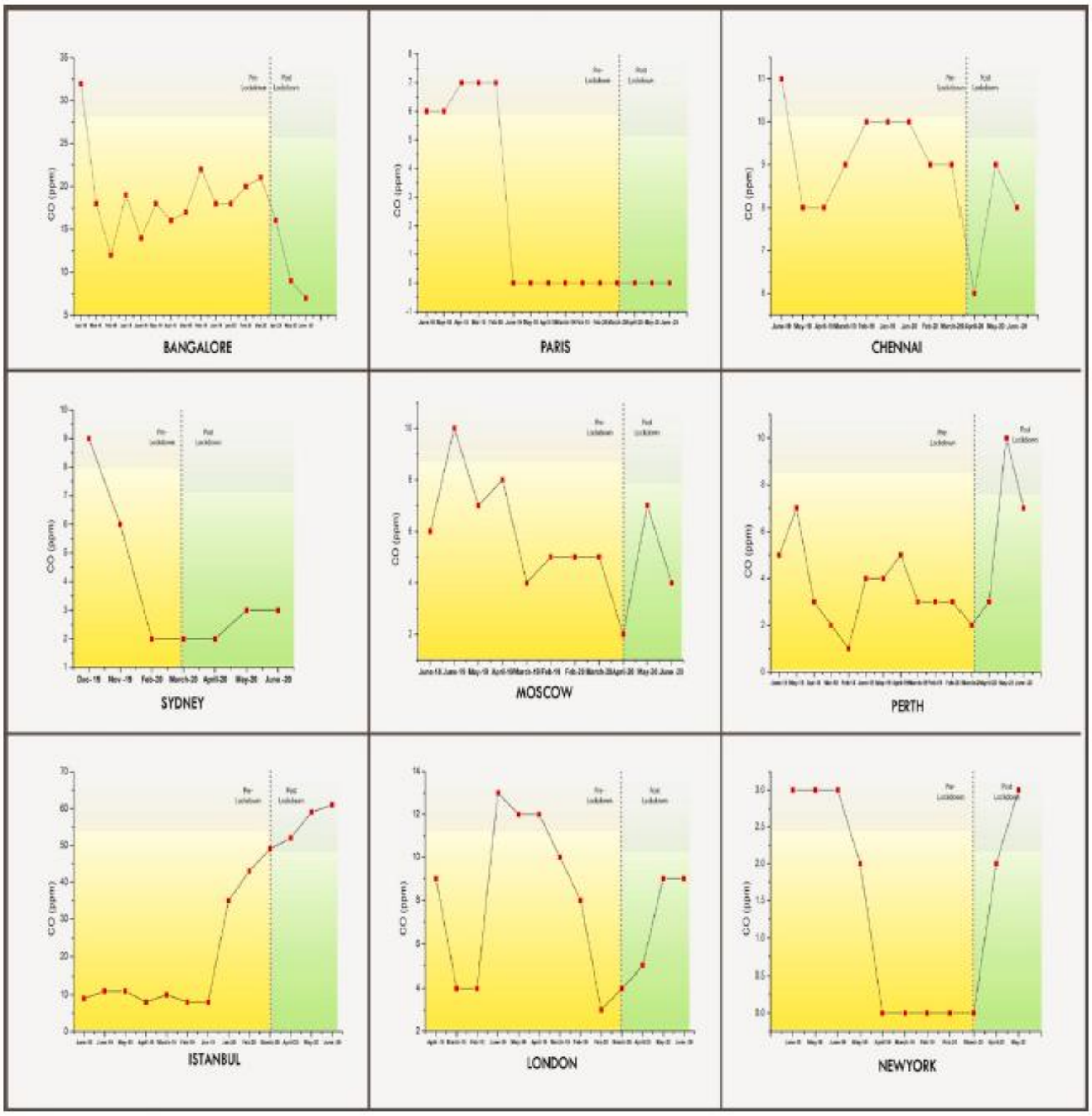

Fig. 10. COVID-19 impact on CO concentration (2018-2020).

3.5.2. Effect of air quality in Brazil during COVID-19

On 16th March 2020, Brazil governor declared the national health emergency due to the rapid transmission of COVID-19. Several cities in Brazil enforced the partial lockdown with some restrictions. Due to the lockdown, the energy consumption and the emission patterns faced a small declination compared to conventional days. Thus, studying the pattern is must to understand the climate change and COVID-19 transmission. Dantas et al., attempted to analyse the effect of the pollutants amid of lockdown in the city Rio de Janeiro, Brazil. Rio de Janeiro was the one of urbanized cities in Brazil which consists of 6.5 million people. Air quality was monitored from 2nd March 2020 to 16th April 2020 by analyzing the pollutants $PM_{2.5}$, PM_{10}, CO, HC, and O_3. Three important stations were considered for their study Bangu, Iraja and Tijuca. Compared to other weeks, the fourth week (23rd to 29th March) reported a higher decline in $PM_{2.5}$ and NO_2 by reporting 17.5% and 21.4% reduction in the pollutants. On the other hand, the drastic increase in the O_3 was observed in the third week (16th to 2nd March). After relaxation of lockdown in the month of April, the reduction in $PM_{2.5}$ and CO still persists due to the reduced movement of the people and the public commuting [**44**]. Another study predicted the effect of air quality during the lockdown in the Sao Paulo state, Brazil. All measurements were collected from industrial areas, Urban I (Marginal Tiete) and Urban II roads (Marginal Pinheiros). The pollutants PM_{10}, NO_2, NOx, SO_2 and O_3 were measured for previous year for making the comparison. Due to the enforced lockdown, there was the drastic reduction the PM_{10}, NO_2 and SO_2. Industrial area reported 12.7%, 5.6% and 32.7% reduction in the pollutants respectively. Compared to the Urban roads, there was no big improvement in the air quality in the industrial areas.

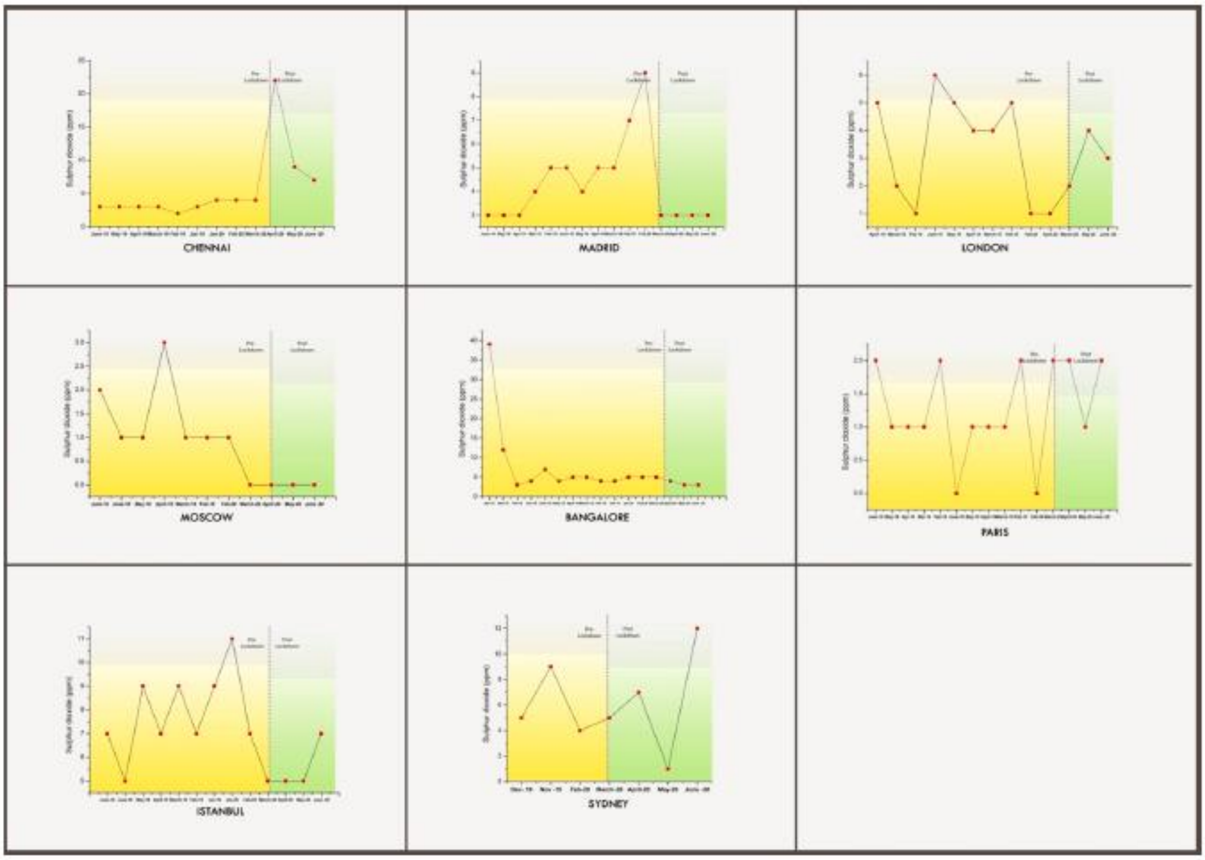

Fig. 11. COVID-19 impact on Sulphur concentration (2018-2020).

With regard to the Urban road I, the pollutants such as $PM_{2.5}$, PM_{10}, CO, SO_2, NO_2 and NO were reduced by 29.8%, 22.8%, 36.1%, 18%, 30.1% and 48.6% respectively. The Urban roads reported least pollution due to the reduction of vehicular movements in the highway [**45**]. David et al predicted the temperature effects on COVID-19 transmission. As it was discussed above, when the temperature was increased, the daily cumulative confirmed cases were reduced by 4.8%. However, their temperature patterns are not clear and it is still needing some serious debate to derive the outcome with less uncertainty. To observe the correlation, the author analyzed the effect of pollution and COVID-19 in all state capitals of Brazil.

4. Discussion

The impact of COVID-19 was a massive blow to the entire world. Despite the origin, the COVID-19 was aggressive in USA, Brazil, UK, Italy, France, Spain and Italy. The number of new confirmed cases has increased dramatically, especially in India and Brazil as on 16th June 2020. Due to the rapid transmission of the infection, the officials have advised to follow the strict restriction in the movement of public. The schools, universities, public halls, gatherings, sports events, shopping malls and non-essential industries were closed owing to health emergencies. This is first time the whole world is going through the lockdown. Based on the transmission and the mortality rates, the date of the lockdown changes from country to country. China is the first nation to enforce the lockdown and followed by many countries due to the high fatality rate. Still now, many cities are under lockdown restriction to reduce the impact of COVID-19. For instance, on June 15, the dynamic city in India, Chennai has enforced the lockdown as phase six from 19th June to 30th June 2020. Owing to the lockdown, the pattern of the energy consumption was drastically changed especially in the populated countries like India and China. Studying the change of the air quality to understand role of non-essential transports is necessary to reduce the pollution and improve the quality of the air we breathe. Further, the improved air quality reduces the health risk including heat and respiratory diseases. This study reviews the improvement in the global air quality during the lockdown. Recently, many authors analyzed the change in the air quality due to the lockdown. However, most of the published articles are on particular geographic locations based on their region of interest as shown in **Table 1**. To understand the pattern of lockdown, it is very essential to study the entire world which will be a key reference in the near future. Hence, we have taken an effort to analyze the air quality in the most cities in the world where the impact of COVID-19 is huge. The air quality data where obtained from the open source portal for selective cities from the period of 2018 to 2020 [**21**]. Each and every city undergoes the COVID-19 lockdown in the different dates. To avoid the uncertainty past three-year data every obtained and compared to analyze the impact. Fig. 7 shows the variation of $PM_{2.5}$ for major cities such as Rome, Istanbul, London, New York, Delhi, Chennai, Melbourne, Paris, Brisbane, Moscow, Sydney and Madrid. All cities showed a drastic reduction in the concentration of the $PM_{2.5}$ pollutants due to the effect of lockdown. A simple comparison was made for the various pollutant concentration of above cities with the values of current data with previous years value. From the **Fig. 7**, it clearly depicts there is a significant decrease in $PM_{2.5}$ concentration levels in all major cities during post lockdown. An average reduction on concentration level during post lockdown in following cities (Rome, Istanbul, London, New York, Delhi, Chennai, Melbourne, Paris, Brisbane, Moscow, Sydney and Madrid) were 27%, 33%, 44.2%, 41.6%, 48.2%, 56.2%, 47.1%, 38.1%, 26.1%, 48.1%,56.25% and 5% respectively as compared to pre lockdown conditions. Out of all cities Madrid showed least improvement in $PM_{2.5}$ concentration level. Cities include Sydney, Chennai, Delhi and Melbourne showed tremendous improvement in $PM_{2.5}$ concentration levels as compared to other cities. PM2.5 is the mixture of solid particles and liquid droplets in the environment. The major contribution of $PM_{2.5}$ is a vehicular emission. Due to the lockdown, the vehicles are kept off roads which lead to reduction of the $PM_{2.5}$. Despite several pollutants the $PM_{2.5}$ causes severe health effects. Due to the COVID-19 impact, the risk of dispersion of the pollutants in the air was reduced. Even though the impact of COVID-19 reduces the pollutant concentration in atmosphere, the concentration of $PM_{2.5}$ seems to be too high as compared with Air quality guidelines of WHO in most of the cities. The concentration of $PM_{2.5}$ in Delhi was found to be 200% higher than WHO air quality guidelines. **Fig. 8** represents the maximum monthly variation of NO2 for major cities. Similar to $PM_{2.5}$, the concentration of the NO_2in most of the cities were reduced exceptionally. From **Fig. 8** the average reduction in concentration of NO_2 during post lockdown situation in the following cities (Berlin, Madrid, Istanbul, Rome, Paris, Chennai, Bangalore and London) were 19.1%, 51%, 39.1%, 21%, 32%, 72%, 51% and 10.2%respectively as compared to pre-lockdown condition. On the contrary the concentration of NO_2 in Perth and Sydney had not shown any improvement owing to COVID-19 impact, whereas New York and Moscow showed minimal increase in NO_2 concentration during the post lockdown situation, but the values of all the cities had not exceed the standards laid down by US Environment protection agency for Zero health impacts on human beings..

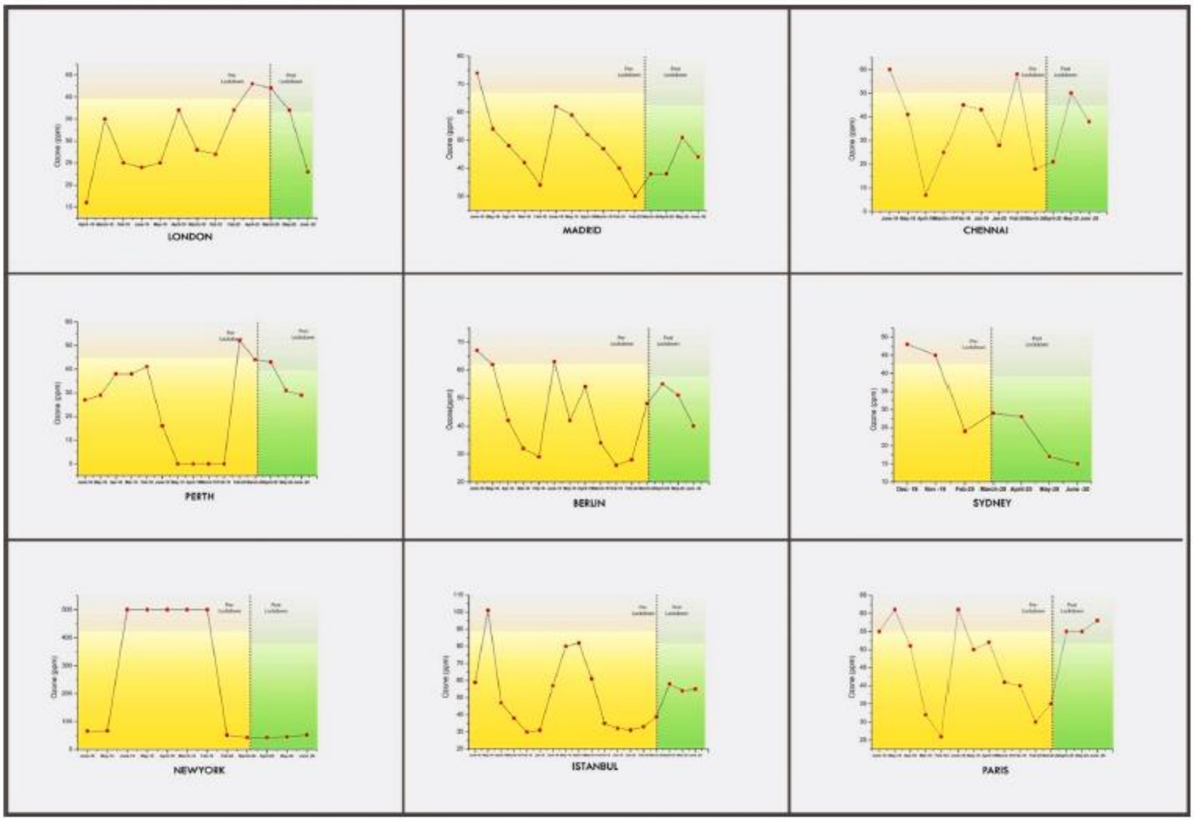

Fig. 12. COVID-19 impact on O_3 concentration (2018-2020).

Understanding the reduction of NO_2 is very crucial since it contributes to the formation of photochemical smog. During the lockdown period, the burning of the fossil fuels, oil and gas were reduced. Due to the closure of the factories the power demand was reduced significantly which cause least burning of coal for power production. Fig. 9 represents the concentration of PM_{10} in various cities. The concentration of PM_{10} in Sydney, Paris and Berlin were reduced significantly as compared to other cities during post lock down situation. The air quality of cities shown in **Fig. 9** had not shown any reduction in PM10 concentration in atmosphere even after lockdown situation. The concentration of PM_{10} in Bangalore, Perth and Istanbul were found to higher than the standards lay down by WHO. Similar to $PM_{2.5}$ and NO_2, the CO concentration is hazard to the World since the gas is tasteless poisonous gas. **Fig. 10** presented the variation of the CO in major cities during pre and post lockdown period. Impact of COVID-19 had not contributed much for the reduction of CO concentration in most of the cities. However, in Perth, Istanbul, and Newyork there is a marginal increase in CO concentration during the Post lockdown situation. CO concentration in atmosphere was mainly due to vehicle emission. Detection of the CO in the air is impossible by the humans since they are tasteless without any smell. Nevertheless, continuous exposure of these gases reduces the oxygen supplied to the body. This typically affects the function of brain and heart. **Fig. 11** shows the maximum monthly concentration of SO_2 pollutants in major cities. Human generates almost 99% of SO_2 in atmosphere. For example, generation of electricity produces enormous amount of Sulphur into the atmosphere and major source was from power plants. Presence of Sulphur dioxide in atmosphere creates breathing difficulties and other related ailments to human beings on short term exposure and it react with other compounds to form as particulate matter. From **Fig. 11**, the concentration of SO_2 in Madrid, Moscow, Bangalore and Istanbul had been reduced significantly, whereas the other cities had not showed any improvement in air quality levels pertaining to SO_2concentration. In fact, the SO_2 concentration in Sydney had grown to minimal level amidst lockdown situation. **Fig. 12** represents the maximum monthly concentration O_3 in atmosphere for most of the cities during Pre and post lockdown situation. Ozone weakens the stratosphere layer and allows the harmful ultraviolet rays to reach the ground surface creates enormous health hazard to the human beings. The concentration of O_3 in New York and Sydney showed tremendous reduction as compared to other cities in **Fig. 12**. On the contrary other cities had not shown any reduction in O_3 maximum monthly Concentration but the average monthly concentration level reduced significantly as compared with pre-lockdown condition. Out of all pollutants, the concentration of $PM_{2.5}$ in atmosphere reduced drastically due to impact of COVID-19. Although there is a reduction in average monthly concentration levels of other pollutants, $PM_{2.5}$ in atmosphere reduces significantly.

5. Conclusion

The COVID-19 pandemic infections swift the world energy pattern drastically. To prevent the transmission of the infection, ban to travel and lockdown of cities had been enforced globally. Quarantine measure and closure of other activities reduce the energy consumption throughout the world. Implementation of the stay-at-home orders reduced the vehicular emission rate, as a result of it, the quality of air we breathe throughout the world was improved significantly. This review describes the environmental pollution effects due to the COVID-19 outbreak globally. This systematic review analysis will be a reference for the pioneers to study the impact of environmental change during the global emergency public event. Further, the role of non-essential emission on the green house can be predicted. The review also shows the importance of the air quality to stop the transmission of the CoV-2. From the crucial analysis, it is observed that the temperature and humidity are also the major factors for higher mortality rates. We stress the officials to concentrate on the highly polluted area where the risk of transmission and the mortality rates are high.

From the obtained analysis, it is evident that the air quality was improved significantly due to the lockdown. Further the concentration of $PM_{2.5}$, P_{10}, NO_2 and CO encountered a sharp decline during the lockdown time. In addition, the O_3 concentration was improved due to the closure of factories and non-essential industries. The quality of the airwas clean and improved. This has been validated from the Sentinel-5 Precursor images. Although the air quality is improved due to the partial lockdown, there are also negative impacts on both economical and mortality rates. Compelling all together, this pandemic taught us a way to save the environment by increasing the remote working.

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