Effect of lockdown amid COVID-19 pandemic on air quality of most polluted cities of Punjab (India)

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In the last month of 2019, the outbreak of a viral disease named COVID-19 started in Wuhan, China. The disease has spread in most of the countries of the world and it was declared as a global pandemic in March 2020 by the World Health Organization (WHO). Many countries implemented countrywide lockdown. COVID-19 has forced many countries to observe complete lockdown. This complete lockdown has improved the air quality significantly due to less human activities. In India, a complete lockdown of 21 days was implemented in phase I (March 25, 2020 to April 14, 2020) to avoid the spread of corona virus disease. Further, this lockdown was extended to phase II (April 15, 2020–May 3, 2020), phase III (May 4–17, 2020) and phase IV (May 18–31, 2020) with some relaxations in restrictions. In the present work, we have analyzed the data of major air pollutants PM_{2.5}, PM₁₀, SO₂, NO₂, CO and O₃ from the three most polluted cities of Punjab for March 03–24, 2020 (before lockdown) *vs.* March 25, 2020 to May 31, 2020 (during lockdown divided into four phases). Further, an extensive comparison of the mean concentration of major air pollutants has been made for the different phases of lockdown including before lockdown period with the same periods in 2019. It is observed that the concentration of PM_{2.5}, PM₁₀, NO₂ and SO₂ has reduced significantly ~50% after first phase of lockdown. As observed in this study, there is an urgent need for interventions across northern India to knockdown air pollutant levels by more than 40% or so by adopting cleaner fuel technology and avoiding poor combustion activities.

Keywords. Air quality; air pollution; lockdown; COVID-19.

1. Introduction

In the end of 2019, first case of corona virus was reported in Wuhan city of China (Sharma *et al.* 2020; Lu *et al.* 2020). Then it reached Europe and rapidly spread across the whole world. A report coming from different regions of the world tells that Severe Acute Respiratory Syndrome Virus (SARS-COV-2) is named as COVID-19 by World Health Organization (WHO). On March 11, 2020, it was declared as a global pandemic by WHO (Shehzad

et al. 2020). It has affected people across the nations worldwide. As per the directions from WHO, Indian government implemented countrywide first phase of lockdown on March 25, 2020. This lockdown was implemented for a duration of 21 days up to April 14, 2020. Further partial lockdown was implemented in different phases II, III and IV from April 15–May 3, 2020, May 4–17, 2020 and May 18–31, 2020, respectively. These lockdowns in India were the first event during the last few decades when almost 1.40 billion people

were locked in their homes. During the first phase of lockdown, all modes of transport including buses, railways and airlines were banned. Industries, construction work, markets and restaurants were closed throughout India. Only essential services, e.g., hospitals, medical stores were open with some conditions. Whereas, some restrictions were relaxed during the subsequent phases of lockdown. The complete lockdown has significant effect on the reduction of air pollution (Bao and Zhang 2020; Kotnala *et al.* 2020). Few studies have reported positive impact of the lockdown on air and water pollution (Gautam and Hens 2020; Singh and Chauhan 2020; Srivastava *et al.* 2020).

Kumari and Toshniwal (2020) investigated the impact of lockdown on the air quality of three Indian cities, namely Delhi, Mumbai and Singrauli. It is shown that the concentration of $PM_{2.5}$, PM_{10} , NO_2 and SO_2 has reduced significantly for these three cities. Otmani *et al.* (2020) studied the variation of air quality parameters before and after the lockdown in Sale city of Morocco. They analyzed that concentration of PM_{10} and NO_2 has decreased by 75% and 49%, respectively. Many studies have been conducted worldwide to analyze the impact of lockdown on air quality (Berman and Ebisu 2020; Gupta *et al.* 2020; Lian *et al.* 2020; Mor *et al.* 2020). According to World quality report (2018–2019), six cities of Punjab (Mandi-Gobindgarh, Amritsar, Jalandhar, Ludhiana, Patiala and Khanna) were among the top 50 polluted cities in the world. Ludhiana, Mandi-Gobindgarh and Patiala were reported the most polluted cities in Punjab. In the present work, we have analyzed the variations in air quality parameters across the three major cities of Punjab (namely Ludhiana, Mandi-Gobindgarh and Patiala) for the different phases of lockdown and compared with before lockdown period. Further, we have compared the mean concentration of major air pollutants for different periods (before lockdown and after lockdown divide into four phases) with the same periods in 2019.

2. Materials and methods

To study the effect of lockdown on air quality, data were collected from the three most polluted cities of Punjab (Ludhiana, Mandi-Gobindgarh and Patiala). The air quality data for the above-mentioned cities have been taken before lockdown (March 3–24, 2020) and after lockdown (March 25–May 31, 2020) from the central pollution

control board (CPCB) online portal (<https://app.cpcbccr.com>). Respirable Suspended Particulate Matter (RSPM) analyzer MP101M (ENVEA, France) has been used to measure the concentration of $PM_{2.5}$ and PM_{10} at all the three sites. This instrument is based on beta gauge measurement method for the continuous measurement of concentration of fine dust in ambient air. The detector is situated at downstream of the filter ribbon which is made up of glass fibre. For the measurement of the concentration of NO_x , analyzer AC32M (ENVEA, France) was used which is based on the chemiluminescence technology. To measure SO_2 and CO concentrations, analyzers AF22e and CO12e (ENVEA, France), respectively, have been used. For the measurement of O_3 , UV photometry technology-based Analyzer O342e from ENVEA, France has been used. The instruments at the three sites have been provided by Punjab Pollution Control Board (PPCB), India. All the instruments used for the measurement of ambient air quality have high accuracy (Manual, ENVEA France). We have collected data for the selected cities during the same period in 2019. These cities were listed in the world's most polluted cities of the year 2018. In order to study the effect of long-range transport of major pollutants, a three-day airmass back trajectories over Ludhiana, Mandi-Gobindgarh and Patiala at 500 m above sea level were retrieved for the whole study period using HYSPLIT model (Stein *et al.* 2015) (<http://ready.arl.noaa.gov/HYSPLIT.php>).

Punjab is the most fertile region in western Indo-Gangetic Plain and is called India's 'bread-basket'. Though Punjab is an essentially agrarian economy, small, medium and few large-scale industrial units have been set up in major cities and towns of Punjab such as Ludhiana, Amritsar, Mandi-Gobindgarh, Dera Bassi, and Rajpura. Ludhiana city of Punjab is known as Manchester of India. Many types of units including textile, auto parts, food products, cycle and steel industries are operationally existing in Ludhiana. As per the report of 2014–2015 (micro, small and medium enterprises; MSME), there are 38,552 registered micro and small units and 153 medium and large units in the district Ludhiana. Mandi-Gobindgarh is known as the steel city of Punjab due to large number of steel industries. There are around 600 industrial units and more than 500 medium to small-sized metal scrap recycling industries. These units are the major local sources of environmental pollution in Mandi-Gobindgarh (Ghosh and Jain 2010; Gupta

Table 1. Details of selected air quality stations in the present study.

Location	Station	Latitude	Longitude
Ludhiana (LDH)	Punjab Agricultural University	30.90	75.85
Mandi-Gobindgarh (MGH)	RIMT University, Mandi-Gobindgarh	30.66	76.29
Patiala (PTA)	Model Town, Patiala	30.2	76.3

Figure 1. Study area of selected cities: Ludhiana, Mandi-Gobindgarh and Patiala (Punjab).

et al. 2013). Patiala is situated southeast of Ludhiana and Mandi-Gobindgarh. But Patiala has less industrial units as compared to Ludhiana and Mandi-Gobindgarh. Patiala region is surrounded by vast agricultural fields. The open burning in the agricultural fields (October–November and mid-April to mid-May) emits large amount of particulate matter and trace gases (CO_2 , CO , CH_4 , N_2O , NO_x , SO_2 and non-methane hydrocarbons) into the atmosphere which perturb the regional air quality and atmospheric chemistry (Sahai *et al.* 2007; Rastogi *et al.* 2014). Details about the location of the selected cities for study are given in table 1 and figure 1. The hourly concentration of key pollutants $\text{PM}_{2.5}$, PM_{10} , SO_2 , NO_2 , CO and O_3 have been used for the present study. 24-hr average of all the pollutants has been calculated to observe the

change between the pre-lock and post-lockdown phases.

3. Results and discussion

In this section, we present the air quality data analysis of three major polluted cities of Punjab before lockdown (March 3–24, 2020) and after lockdown period (March 25–May 31, 2020 divided into four phases). Figure 2(a–f) represents the daily average concentration of $\text{PM}_{2.5}$, PM_{10} , SO_2 , NO_2 , CO and O_3 between March 3, 2020 and May 31, 2020 in Ludhiana, Mandi-Gobindgarh and Patiala. The 24 hrs average level of $\text{PM}_{2.5}$ (figure 2a) in Ludhiana varied from 28 to 98 $\mu\text{g}/\text{m}^3$ before lockdown and after lockdown period (phase I), it reduces to 14–41 $\mu\text{g}/\text{m}^3$. The highest level of $\text{PM}_{2.5}$

Figure 2. (a–f) Daily average concentration of PM_{2.5}, PM₁₀, NO₂, SO₂, CO and O₃ between March 3, 2020 and May 31, 2020 over Ludhiana, Mandi-Gobindgarh and Patiala.

in Ludhiana was recorded as 98 $\mu\text{g}/\text{m}^3$ on March 5, 2020 and lowest level was recorded as 28 $\mu\text{g}/\text{m}^3$ on March 7, 2020 before lockdown. On March 29, 2020, PM_{2.5} level after lockdown (phase I) reduces

to its lowest value 14 $\mu\text{g}/\text{m}^3$. In Mandi-Gobindgarh, the PM_{2.5} level ranged from 23 to 190 $\mu\text{g}/\text{m}^3$ before lockdown and after lockdown (phase I) it reduces to 19–72 $\mu\text{g}/\text{m}^3$. On March 29, 2020, PM_{2.5}

Figure 3. Variation in mean concentrations of PM_{2.5}, PM₁₀, NO₂, SO₂, CO and O₃ before lockdown and different phases of lockdown over Ludhiana, Mandi-Gobindgarh and Patiala.

Table 2. Revised Indian national air quality standards (INAQS).

Pollutants ($\mu\text{g m}^{-3}$)	Time weighted average	Concentration of ambient air	
		Industrial, residential and other areas	Economically sensitive area (notified by GoI)
PM ₁₀	24 hrs	100	100
PM _{2.5}	24 hrs	60	60
NO ₂	24 hrs	80	80
SO ₂	24 hrs	80	80
O ₃	1 hr	180	180
CO (mg m^{-3})	8 hrs	02	02
	1 hr	04	04

Source: CPCB 2015.

level in Mandi-Gobindgarh recorded its lowest value 19 $\mu\text{g}/\text{m}^3$. The level of PM_{2.5} before lockdown and after lockdown (phase I) in Patiala was 18–88 and 17–42 $\mu\text{g}/\text{m}^3$, respectively, showing a significant decline. It is observed from figure (2b) that PM₁₀ in Ludhiana before lockdown varied from 35 to 105 $\mu\text{g}/\text{m}^3$ and after lockdown (phase I), it decreased to 25–64 $\mu\text{g}/\text{m}^3$. The minimum average value of PM₁₀ after lockdown (phase I) in

Mandi-Gobindgarh and Patiala was recorded as 26 and 17 $\mu\text{g}/\text{m}^3$, respectively.

The range of NO₂ (figure 2c) in Ludhiana, before and after lockdown (phase I) was 20–83 and 19–25 $\mu\text{g}/\text{m}^3$, respectively. In Mandi-Gobindgarh, average value of NO₂ shows a slight increase. This may be due to the emission of gases from large number of iron and steel industries and power plant in the region. In Patiala, NO₂ level decrease from 5–12 to

1–6 $\mu\text{g}/\text{m}^3$ after lockdown (phase I). From April 10 to 14, 2020, NO_2 level in Patiala has been recorded to its lowest value 1 $\mu\text{g}/\text{m}^3$. The average value of SO_2 in Ludhiana and Mandi-Gobindgarh decreased from 13.2 and 20.3 to 5.9 and 7 $\mu\text{g}/\text{m}^3$, respectively. It is evident from figure 2(e) that average value of CO in Ludhiana and Patiala is significantly lower after lockdown (phase I) as compared to before lockdown. After lockdown (phase I), the average value of CO decreased to 7–14 $\mu\text{g}/\text{m}^3$ for Ludhiana.

It is observed from figure 2(f) that after lockdown (phase I), average value of O_3 in Ludhiana increased from 13–23 to 16–40 $\mu\text{g}/\text{m}^3$. In Mandi-Gobindgarh, the maximum value of O_3 was recorded (46 $\mu\text{g}/\text{m}^3$) on April 14, 2020. Many studies from different countries showed that during lockdown, average concentration of O_3 increases (Srivastava *et al.* 2020; Xu *et al.* 2020). The maximum increase in O_3 was 46.6% in Ludhiana.

Ozone chemistry depends on the concentration of Nitrogen oxides (NO_x), volatile organic compounds (VOCs) as well as solar radiation (Seinfeld and Pandis 1998; Lee *et al.* 2002). After implementation of lockdown, NO_x as well as VOC concentrations decreased due to sudden full stop on anthropogenic activities, but solar radiation increased. Therefore, the concentration of ozone increased due to increase in solar radiation (Dang and Liao 2019; Li *et al.* 2019). It is observed that the increase in the concentration of O_3 is relatively lower than 2019 due to decrease in concentration of its precursors except in phase 2 over Ludhiana and phase 4 over Mandi-Gobindgarh. This difference in the concentration of O_3 is not significant in the case of Patiala.

Figure 3 shows the variation in mean concentrations of all the pollutants before and after lockdown (phase I) in Ludhiana, Mandi-Gobindgarh and Patiala. Due to less activity in transport sector and industrial activities, concentrations of the major air pollutants ($\text{PM}_{2.5}$, PM_{10} and NO_2) have significantly reduced after lockdown (phase I). The average value of $\text{PM}_{2.5}$ was 44.0 and 25.5 $\mu\text{g}/\text{m}^3$ for Patiala before and after lockdown (phase I), respectively. The average value of $\text{PM}_{2.5}$ was 80.9 $\mu\text{g}/\text{m}^3$ in Mandi-Gobindgarh before lockdown which reduces to 40.69 $\mu\text{g}/\text{m}^3$ after lockdown (phase I). The average value of PM_{10} was found to be 93.6 $\mu\text{g}/\text{m}^3$ in Mandi-Gobindgarh before lockdown and 45.2 $\mu\text{g}/\text{m}^3$ after lockdown (phase I). The maximum average value of NO_2 was reported in Ludhiana before lockdown. In case of Mandi-Gobindgarh,

Figure 4. Percentage change in average concentrations of air pollutants before lockdown and after lockdown (phase I) in Ludhiana, Mandi-Gobindgarh and Patiala.

there was a slight increase in the level of NO_2 after lockdown (phase I). For SO_2 , the average value decreased from 20.3 to 7.7 $\mu\text{g}/\text{m}^3$ in Mandi-Gobindgarh after lockdown (phase I). The average value of CO in the Ludhiana reduced from 20.3 to 9.1 $\mu\text{g}/\text{m}^3$ after lockdown (phase I) with a maximum decrease of 64.5%. It is clear from figures 2 and 3 that during the days of lockdown (phase I), average value of all the key pollutants was lower than the National Ambient Air Quality Standards (NAAQS) table 2.

Further in this paper, the analysis has been extended to phase II, III and IV of lockdown. The major decrease in the concentration of all the air pollutants was observed in the first phase of lockdown in comparison to the other three phases. This could be due to the relaxation in the later phases of lockdown. It has been observed from figure 3 that there is an increase in the concentration of air pollutants during phases III and IV as compared to the other phases. Two major reasons for this increase are the burning of Rabi crop residue and dust storm in the month of May. Thus, dust events might have contributed for enhancement of $\text{PM}_{2.5}$ and PM_{10} concentration during phase III and IV (Yadav *et al.* 2017; Sarkar *et al.* 2019). It is observed that there is an increase in the concentration of O_3 March onwards, but when this trend was compared with the previous year, it has been noticed that a similar trend is there in 2019.

Figure 4 represents the percentage change in all the pollutants for the selected cities of Punjab after lockdown (phase I). It is observed that most significant decline in Ludhiana for $\text{PM}_{2.5}$, PM_{10} , NO_2 and CO was 54.8%, 54.8%, 60.7% and 64.5%, respectively. The maximum reduction in the level of SO_2 in Mandi-Gobindgarh after lockdown (phase I) was 62.1%. But the concentration of O_3 increases by 46.6% in Ludhiana.

Figure 5. (a–q) Comparison of mean concentrations of air pollutants for different time periods in 2019 and 2020 for three cities of Punjab.

From March onwards, meteorological parameters also change significantly with time. So one may also conclude that the decrease in the concentration of the major air pollutants is due to this

change in meteorological parameters. Therefore, we have examined the variation in the concentration of major air pollutants for four phases of the lockdown in 2020 and compared with the

Figure 5. (Continued.)

Figure 6. Three-day backward air mass trajectories at 500 m over selected study sites before and after lockdown.

corresponding periods in 2019. It has been observed from figure 5(a–q) that during 2019, there is no significant change in the mean concentration of almost all the air pollutants from March to May for the selected cities of Punjab. It is also investigated that in 2019, the concentration of some air pollutants has shown increasing trend from March to April. But on the other hand, in 2020 there is significant decrease in the concentration of all major air pollutants before and after lockdown (phase I). Thus, this decrease is attributed solely to the lockdown imposed in 2020 rather than the changes in meteorological parameters. It is observed from figure 5(d) that NO_2 in Ludhiana shows much higher concentration in 2020 with respect to 2019 during lockdown phase. The increase in NO_2 concentrations over Ludhiana may be due to large industries.

To study the influence of long-range transport of atmospheric pollutants, the air mass back trajectory analysis was performed at all the three sites. The average values of all the major pollutants showed a significant decrease after lockdown. It is observed that the air motion is mostly in northwest and west direction travelled from Afghanistan, Tajikistan and Pakistan via Rajasthan to Punjab (figure 6). The air quality for the three cities was significantly influenced by long-range transport. The seasonal pattern of air mass trajectories over Patiala site has been examined in a previous study (Bansal *et al.* 2019).

4. Conclusion

COVID-19 has affected adversely public health and the economy worldwide. On the other side, it has positive impact on nature as air pollution after lockdown has significantly reduced. In the present study, the effect of various phases of lockdown on the air quality of three major polluted cities of Punjab has been investigated. It is observed that there is a significant decrease in the levels of $\text{PM}_{2.5}$, PM_{10} , NO_2 and SO_2 for the three cities after phase I lockdown. Furthermore, the two most polluted cities Ludhiana and Mandi-Gobindgarh showed the maximum decrease in key air pollutants after lockdown (phase I). It has been observed that during the month of May (phases III and IV), level of air pollution arises due to relaxations in lockdown as well burning of rabi crop residue. It is also observed that after lockdown the concentration of O_3 has increased for the three selected cities. The rise in concentration of O_3 could be due to increase

in solar radiation. By comparing the data for the same periods in 2019, it is concluded that decrease in the concentration of air pollutants is mainly due to lockdown implemented. With the decrease in air pollution, many health issues like cardiovascular and respiratory diseases can be significantly reduced. As per the WHO report, around ~ 7 million of the premature deaths globally are due to air pollution. So, with the decrease in air pollution due to lockdown can reduce mortality due to pollution. By taking lesson from this situation, state and central governments can formulate a strategy to reduce air pollution. The responsibility of the citizens is to avoid undue contribution to air pollution. People could be motivated to celebrate ‘No Vehicle Day’ once a month.

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Author statement

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