Proceeding Paper

Impact of COVID-19 Lockdown on the Air Quality in the Northwestern Himalaya, India †

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Abstract: The outbreak of corona virus or COVID-19 pandemic has created a serious health concern worldwide. The world was forced to shut down. India witnessed nationwide lockdown from 25 March 2020 to 31 May 2020 in four different phases. Industries were shut and vehicle movement was restricted both in inter and intra state. In the present study, concentration of criteria pollutants, Surface ozone (O_3,), Sulphur dioxide (SO_2), Carbon monoxide (CO), Nitrogen Dioxide NO_2 and Total Suspended Particles (TSP)were monitored in pre lockdown period (PLD) 1 January–24 March 2020 and during lockdown (LD) 25 March–31 May 2020 were analyzed. Total Suspended Particles (TSP) were monitored by gravimetric method using Respirable Dust Sampler (RDS), NO_2 was measured using modified Jacob and Hochhesier method while sulphur dioxide, carbon monoxide and surface ozone were monitored using online gas analyzers manufactured by thermo fisher scientific at Mohal Kullu Valley of northwestern Himalaya which is a semi urban area. The results revealed reduction of 66.24%, 37.32%, 27.02% and 16.67% in CO, TSP, NO_2 and SO_2 respectively during lockdown as compared to pre-lockdown while surface ozone (O_3) showed an increase in concentration during lockdown period as compared to pre lockdown. The overall air quality improved during the lockdown period when compared to the pre lockdown period in the valley indicating how the air quality is affected by anthropogenic activities in the area.

Keywords: COVID-19; pandemic; lockdown; pollutants; sulphur dioxide; Ozone; Himalaya

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1. Introduction

Ambient air quality improved during the COVID-19 lockdown in the Kullu valley of northwestern Indian Himalaya. The COVID-19 pandemic which originated in a city of Wuhan in China has quickly spread to worldwide. Studies suggest that citywide closures are effective to control the spread of this virus (Liu et al., 2020). On January 30, 2020. India reported its first COVID-19 case in Kerala (Andrew et al., 2020). Soon India reported spreading of Covid-19 infection by beginning of March 2020.The Prime Minster of India Sh. Narender Modi announced a Janta Curfew on 22 March 2020 followed by a nationwide lockdown from 25 March 2020 to prevent the spread of the virus. Industries were shut and vehicle movement was restricted. The ambient air pollution decreased restrictions were imposed (Chen et al., 2020; Karuppasamay 2020; Singh and Chauhan, 2020). In the period of lockdown, data acquired from 128 air quality stations across United States revealed reduction of nitrogen dioxide (NO2) and carbon monoxide (CO) was observed in lockdown (Chen et al., 2020). Kullu is one of the famous tourist destinations in northwestern Indian Himalayan Region (IHR). The Kullu Valley has seen an increase in the number of tourists in the past years (Kuniyal et al., 2004). There were about 30,000 vehicles registerd in Kullu Valley till 2009, there has been a drastic increase in number of vehicles in the valley every year from 2009 onwards (Sharma et al., 2009). But in the year 2020, there were no tourist in the peak month of tourist season in the valley due to restrictions. A recent study of china has reported that a regional level lockdown offers an opportunity to examine relationship between anthropogenic activities and air pollutants which can help policymakers to reduce pollution levels in future (Wang et al., 2021). Due to increase in the number of tourists and vehicles, air quality has degraded in the past few years in the Kullu valley. Increase in number of vehicles, uncontrolled traffic and deforestation had led to degradation in air quality of Kullu (Kuniyal et al., 2003). Exposure to ambient pollutants for long and short term have adverse health effect as established in the epidemiological literature

(Zhang et al., 2019). As the year 2020 was the first time that there was no tourist in the valley and the vehicle movement was restricted for local people as well from 25 March 2020 to 31 May 2020.Theerefore, the present study will help in determine how increase in number of vehicles due to tourism and anthropogenic sources affect the air quality of the Kullu valley. Pollutants such as, SO_2, surface ozone (O_3), NO_2 and CO are criteria pollutants which can be used to determine air quality.

2. Study Area

The experimental site where the present study carried out was at G.B Pant National Institute of Himalayan Environment, Himachal Regional Centre, Mohal-Kullu (31°54′ N,77°07′ E).It is situated in Kullu Valley which is 5 Km south to Headquarter Kullu which is a famous tourist destination. (Figure 1). It is one of the stations for monitoring ambient air quality using online gas analyzer by Indian Space Research Organization (ISRO) under ISRO –AT-CTM Program. The Kullu Valley consists of Beas basin. This Beas valley stretches from lower beas basin Larji (957 m) upto upper beas basin i.e Rohtang Crest (4038 m) (Kuniyal et al., 2003).This region is a rain shadow region in himalayas as this region is flanked by North-South running mountain region on either side.In the year 2008 kullu valley hosted 2.12 million tourists which clearly indicate how tourism is growing in the valley from past few years. (Sharma et al., 2009). The Kullu valley which earlier was an example of clean valley with clean air is now on the way of capital city Delhi due to increase in anthropogenic activities such as increase in pollution due to traffic, buildings construction, increase in industries hydropower and tourist related activities.

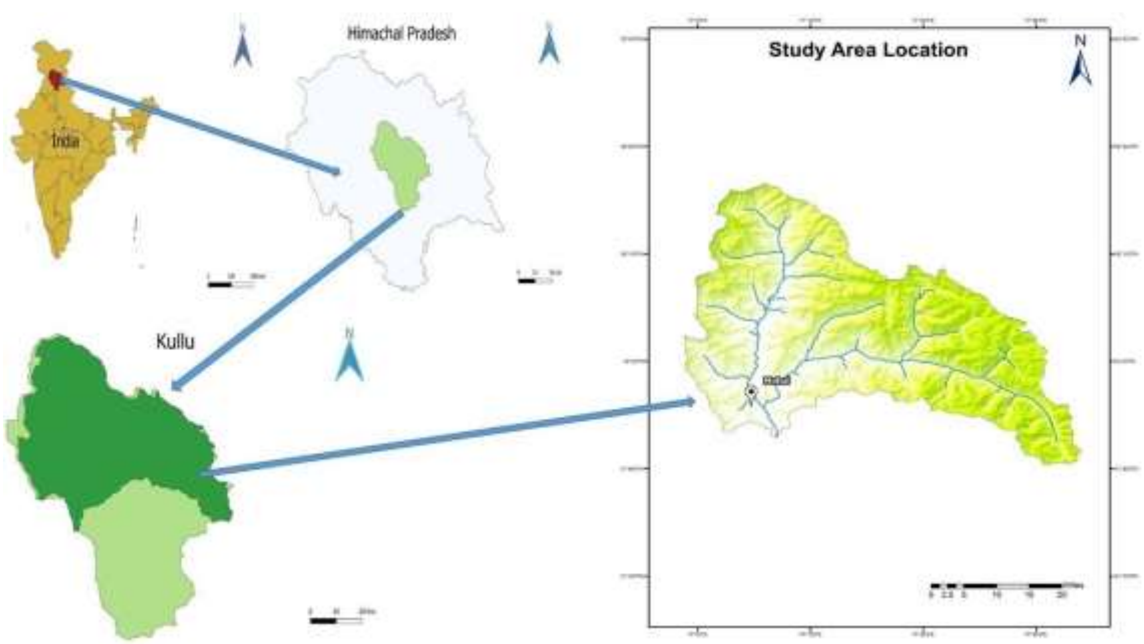


Figure 1. Location of the Study Area.

3. Methodology

TSP is the particle (particulate matter) diameter less than 50–100μm. It was measure by gravimetric method using RDS in which particulate matter are collected in Whatman filter paper. The filter paper is weighed before and after sampling particulate matter and concentration of RSPM is finally obtained in μg/m^3 with difference in weight of filter paper before and after sampling while NRSPM was collected in cone of RDS which was similarly weighed before and after sampling. The difference in weight is divided by volume of air sampled and NRSPM is also expressed in μg/m^3. TSP is the sum of RSPM (particulate matter on filter paper) +NRPSM (coarse dust in the cone)

$$TSP = RSPM + NRSPM$$

where RSPM = Respirable Particulate matter NRSPM = Non Respirable Particulate Matter.

Jacob and Hochhesier method was used to determine concentration of Nitrogen Dioxide. Solution of Sodium hydroxide and sodium nitarate was prepared and ambient Nitrogen Dioxide NO_2 was bibbled through it. Nitrite ion was reacted with phosphoric acid, sulfanilamide, and N-(1-naphthyl)-ethylene diamine di-hydrochloride (NEDA) to measure the concentration of NO_2 produced during sampling.

Surface ozone (O_3) was monitored through Thermo scientific Model 49i and operates on the principle that ozone molecule absorbs UV light at wavelength of 254 nm.The degree to which the U.V. light is absorbed is directly related to ozone concentration as described by Beer-Lambert law (Keefe et al., 2005).

$$I/I_0 = e^{-klc}$$

where

k = molecular absorption coefficient, 308 cm^{-1}(at 0 °C and 1 atmosphere) L = length of cell, 38 cm

C = concentration of ozone

I = Ultraviolet light intensity of Sample with ozone (sample gas) I0 = Ultraviolet Light intensity of sample without ozone (reference gas).

The measurement concentration of Ozone Analyzer ranges from 50 ppb to 1000 ppb and averaging time 10 to 300 s with flow rate 1 to 3 L/min. (Thermo scientific model 49i manual).

For Sulphur Dioxide, the online analyzer used is Thermo scientific Model 43i.This model operates on principle that SO_2 molecule absorbs U.V light and become excited at one wavelength, then decay to lower energy state emitting U.V light at different wavelength, specifically (Fluorescence) (Lv et al., 2018).

$$SO_2 + hv_1 \text{---->} SO_2^{*} \text{-------} SO_2 + hv_2$$

Its measurement concentration varies from 50 ppb–1000 ppb with average time period 100–300 s with flow rate 0.5–1.0 L/min.

The concentration of carbon monoxide (CO) is measured using Thermo scientific Model 48i. It is based on the principle that CO absorbs infrared radiation at a wavelength of 4.6 micron because infrared absorption is a non –linear measurement technique. The basic analyzer must be transformed into a linear output. It has an internally stored calibration curve to accurately linearize the instrument output over any range upto concentration of 10,000 ppm. Its measurement concentration ranges from 0–1 ppm to 100 ppm averaging time 10 to 3000 s and flow rate 0.5 to 2 L/min.

The analyzers having their respective model 43i, 48i an 49i, are connected to PC which uses Envidas software. The gases are monitored continuously for 24 h. These pollutants were monitored during the COVID-19 lockdown using this software. Further, analysis of data was made to study the concentration of pollutants during lockdown. The data was analyzed for the period from 1 January–24 March 2020 (Pre lockdown Period), 25 March 2020 to 31 May 2020(Lockdown period) and 1 June–31 December 2020 (Post lockdown period) and the concentration of pollutant ozone and carbon monoxide is further converted into μg/m^3 from ppb and ppm. The formula used in conversion of ppb to μg/m^3.

$$\mu g/m^3 = (ppb)*(12.87) * M/(273.15 + °C)$$

where M = Molecular weight of gas °C = Temp (25 °C)

The formula used for conversion of ppm into μg/m^3 is

$$mg/m^3 = 0.0409 *ppm *M$$

where 'M' is molecular weight of Gas.

Air Quality Index (AQI)

To understand the overall improvement in air quality, Air Quality Index (AQI) was calculated. AQI uses SO_2, O_3, NO_2, $PM_{2.5}$, PM_{10}, NH_3, of which minimum three pollutants at least need to be available. The concentrations are converted to number on a scale 0–500.The index AQI (AQIi) for each pollutant like NO_2, CO, SO_2, was used as under:

$$AQIi = INHI - InLO/BHI\text{-}BLO^* (Ci - BLO) + INLO$$

where Ci is the concentration of pollutant 'i'; BHI and BLO are breakpoint concentration greater and smaller to Ci and and INHI and INLO are corresponding AQI values. The overall AQI is maximum AQIi, and the corresponding pollutant is the dominating pollutant. The AQI is divided into six categories; good, satisfactory, moderate, poor, very poor and severe depending on whether the AQI falls between 0–50, 51–100, 101–200, 201–300, 301–400 and 401–500, respectively (Sharma et al., 2020).

4. Results and Discussion

4.1. Air Quality during COVID-19 Lockdown

Several previous studies have analyzed the indirect effect of COVID-19 on the air quality (Fattorni and Regoli 2020; Bashier, 2020; Collivignarelli et al., 2020). From a recent study on black carbon in the Kullu valley shows a decrease in concentration of black carbon during COVID-19 lockdown (Gogoi et al., 2021), also studies carried out in the Indo Gangetic plain during COVID-19 lockdown shows a reduction in pollutants as well as in AOD (Aerosol Optical Depth) (Thomas et al., 2021). Most of the recent studies during COVID-19 lockdown period show a decrease in concentration of pollutants such as NO_2, SO_2, CO, $PM_{2.5}$ and PM_{10} in most of the cities, the reason being reduction of transportation, industry and commercial activities (Fu et al., 2020). A recent study on concentration of $PM_{2.5}$ shows a decrease in concentration of $PM_{2.5}$, during COVID-19 lockdown (Patra et al., 2021). A full lockdown was announced on 24 March at 8.00 p.m. (IST) which was to begin from 25 March 2020 (Ray & Subramanian, 2020).

4.1.1. Total Suspended Particles (TSP)

Figure 2a illustrates ambient concentration of TSP during pre-lockdown, lockdown and post lockdown for the year 2020 and in the same time period for year 2019 (24 h average). Average ambient concentration of TSP during pre-lockdown period was 94.5 ± 5.58μg/m^3 in 2020 (80.4 ± 14.91μg/m^3 in 2019 for same period). On the other hand, during lockdown period, value decreased to 59.2 ± 3.47 μg/m^3 in 2020 (110.8 ± 12.25 μg/m^3 in 2019) which was further increased during post lockdown as high as 82.5 ± 4.56μg/m^3 2020 (95.3 ± 8.78 μg/m^3 in 2019).

The diurnal variation of TSP during pre-lockdown and lockdown period of the year 2020 shows a decline in concentration during lockdown period (Figure 2b). TSP showed a low concentration during lockdown period.

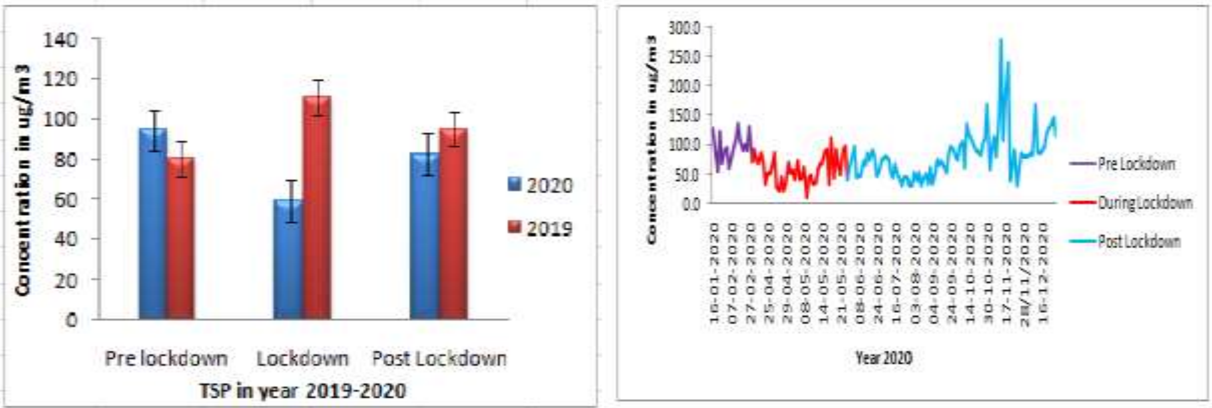


Figure 2. (**a**) Average concentration (**b**) Diurnal Variation of TSP during pre-lockdown, lockdown and post lockdown period for the year 2020.

4.1.2. Nitrogen Dioxide

Several recent studies have indicated a decrease in NO_2 as anthropogenic activites (Vehicle movement) was reduced. Nitogen dioxide showed average concentration 3.7 ± 0.2 μg/m^3 during pre lockdown (1 Jan–24 March 2020), which was decreased to 2.7 ± 0.1 μg/m^3 during lockdown, further increased to 4.6 ± 0.5 μg/m^3 during post lockdown (Figure 4a).

4.1.3. Sulphur Dioxide

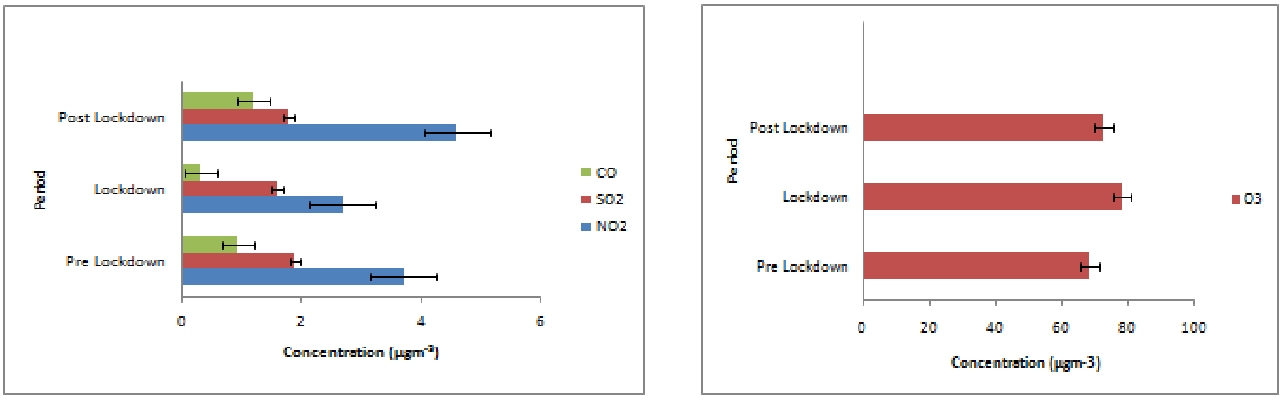
Sulphur dioxide showed a concentration of 1.910 ± 0.01 μg/m^3 during pre-lockdown (1 January 2020–24 March 2020). This value decreased to 1.622 ± 0.01 μg/m^3 (24 h avg) during lockdown and 1.805 ± 0.04 μg/m^3 during post covid lockdown (1 June–31 December) (Figure 4b).

4.1.4. Carbon Monoxide (CO)

Carbon Monoxide showed a concentration of 0.951 ± 0.10 mg/m^3 during pre-lockdown (1 January 2020–24 March 2020). ((units converted from ppm to mg/m^3) There was a decrease in concentration to 0.321 ± 0.02 mg/m^3 (8 h avg.) during lockdown (Figure 4c) and 1.203 ± 0.14 mg/m^3 during post lockdown. There was a decrease in concentration of CO during lockdown period in the year 2020 as the vehicle movement was restricted in the valley.

4.1.5. Surface Ozone

As most of the studies during lockdown period showed a decrease in concentration of pollutants such as PM_{10}, $PM_{2.5}$, NO_2, and SO_2. Studies have also shown an increase in concentration of surface ozone during lockdown period (Torkhmulla et al., 2021). Surface Ozone showed a maximum concentration of 68.44 ± 0.04μg/m^3 during pre-lockdown (1 January 2020–24 March 2020). Further, during lockdown while all other pollutants showed decrease in their concentration, surface ozone showed increase in its concentration. The maximum concentration of surface ozone was 78.25 ± 10.63 μg/m^3 (units converted from ppb to ug/m^3) during lockdown (25 March–31 May 2020) for 8 h average (Figure 4d) and 72.73 ± 7.39μg/m^3 during post lockdown (1 June–31 December 2020). The concentration of surface ozone (O_3) increased during the lockdown period in most of parts of the world (Cristina, 2020; Dantas, 2020; Mahato, 2020; Wang et al., 2020b). The reason behind this reverse trend of O_3 concentration was identified as particulate matters (PM) concentrations decreased. Photochemical activities increased due to reduction in particulate matter in air,which caused photo ooxidation which lead to higher production of ozone or due to increase in temperature during the lockdown period (Dang and Liao, 2017; Li et al., 2018).

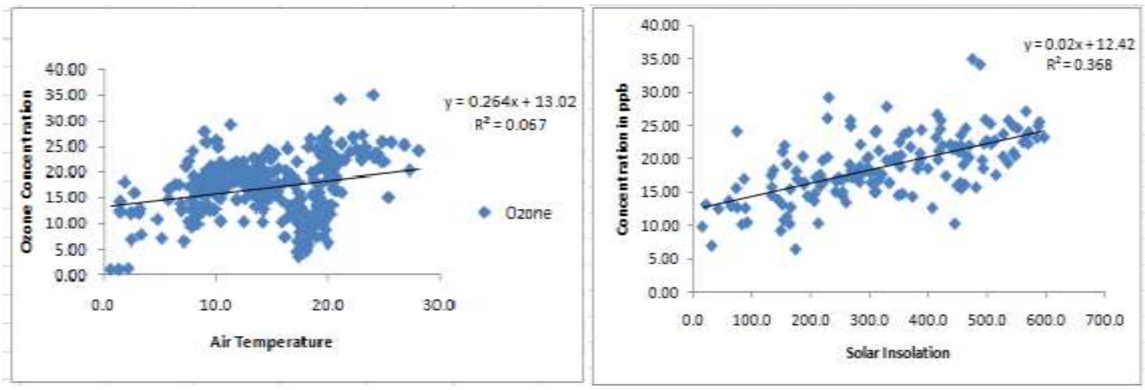


(**a**) (**b**)

Figure 3. (**a**) Maximum average concentration of NO2, SO_2, CO (**b**) Surface Ozone during pre lockdown (1 January–24 March), lockdown (25 March 2020–31 May), post lockdown (1 June–31 December).

4.1.6. Correlation of Meteorological Parameters with Pollutants Correlation between Surface Ozone and Air Temperature and Solar Isolation

In the present study area on daily average basis, surface O3 shows a positive correlation with temperature and solar insolation, which shows the effectiveness of photochemistry (Figure 4a,b). Thus a increase in temperature can be a possible reason for increase in concentration of ozone during lockdown.

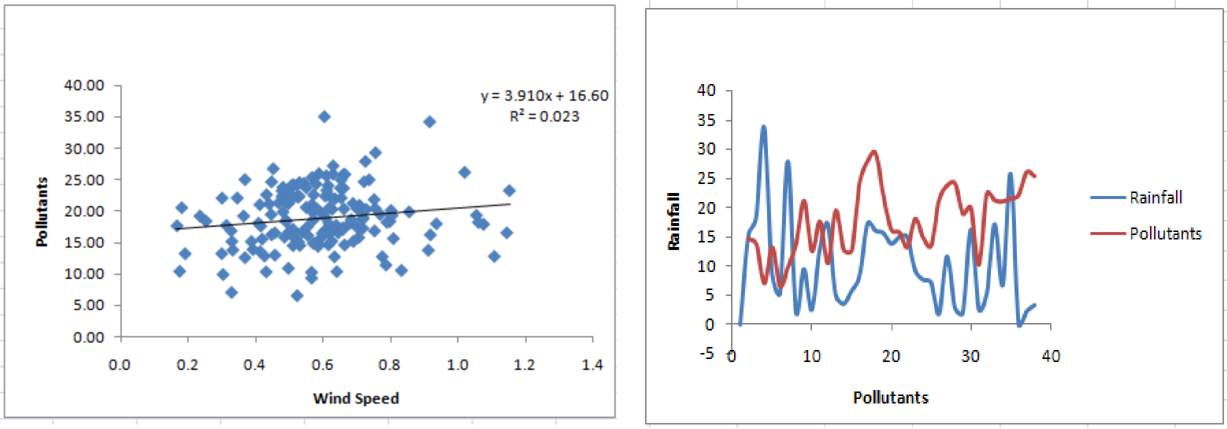


(**a**) (**b**)

Figure 4. Correlation between Surface Ozone, air temperature and solar insolation.

4.1.7. Wind Speed and Rainfall

In the present study area i.e., Mohal in kullu Valley wind speed is very slow so it does not impact the concentration of pollutants while rainfall showed negative correlation with pollutants. Sometimes there is a temporary decrease in concentration of pollutants due to rainfall. The average rainfall in the valley during pre lockdown period was 326.7 mm (IMD) while it was 96.5 mm during lockdown period which indicates that the decrease in pollutant was due to reduction in anthropogenic activities.



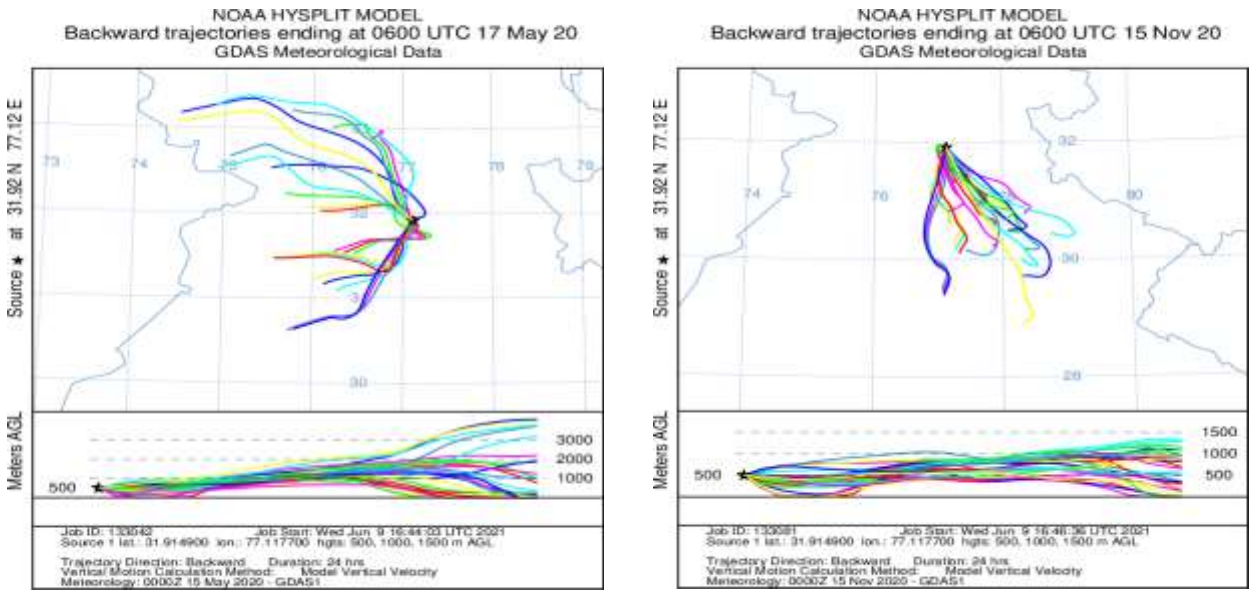
(**a**) (**b**)

Figure 5. Correlation between pollutants, wind speed and rainfall.

4.1.8. Long Range Transport (Hybrid Single Particle Langrangain Integrated Tajectory Model)

Using Hybrid Single-Particle Langrangian Integrated Trajectory (HYSPLIT) model derived by National Oceanographic and Atmospheric Administration (NOAA), back trajectories were drawn to highlight long range transport source during pollution episodes. The trajectories were drawn during maximum episode's value during lockdown on 17 May, 2020 at Mohal and during post lockdown episode value on 15 November, 2020 at Mohal during high pollution days.

In and around the study area, maximum values of particulate pollutants (TSP) were observed as 110.0µg m^{-3} on 17 May, 2020 where the back trajectory was coming from South Asia from the dry area of Pakistan. The trajectory, thereafter, passed through, Jammu, Pathankot (India), Kangra district of Himachal Pradesh (India) and ultimately reached at Mohal and also areas from punjab (Figure 6a). Meanwhile, during post lockdown TSP showed maximum value 279.0µg m^{-3} on 17 November 2020 where the back trajectory was coming from the areas of Moradabad, the trajectoy thereafter passed areas of muzzafarnagar, haridwar, dehradun,ultimately reaching Mohal (Figure 6b).



(**a**) (**b**)

Figure 6. Back trajectories using HYSPLIT Model relating with highest particulate pollutants. (a) during lockdown, and (b) post-lockdown.

4.1.9. Assessment of AQI

Air Quality Index is used to determine air quality status. It converts air quality data of various pollutants into a single value. The air quality index is further divided into 6 categories which are determined by the value of ambient concentration of air pollutants and their adverse effect (health breakpoints). The categories of Air quality Index ranges from good to severe. AQI sub-index and health breakpoints are evolved for eight pollutants, namely, PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3 and Pb for which short term (upto24 h) National Ambient Air Quality Standards (NAAQS) are prescribed. Based on measured ambient concentration, sub-index is calculated which is a linear function of concentration. The worst sub-index determines the overall AQI. AQI categories and health breakpoints for the pollutants are given below in Table 1.

Table 1. AQI categories and health breakpoints for the pollutants (CPCB 2014).

AQI Category (Range)	**PM10 24-hr**	**PM2.5 24-hr**	**NO2 24-hr**	**O3 8-hr**	**CO 8-hr**	**SO2 24-hr**
Good (0–50)	0–50	0–30	0–40	0–50	0–1.0	0–40
Satisfactory (51–100)	51–100	31–60	41–80	51–100	1.1–2.0	41–80
Moderate (101–200)	101–250	61–90	81–100	101–168	2.1–10	81–380
Poor (201–300)	251–350	91–120	181–280	169–208	10.1–17	381–800
Very Poor (301–400)	351–430	121–250	281–400	209–748	17.1–34	801–1600
Severe (401–500)	430+	250+	400+	748+	34+	1600+

Note: CO concentration are expressed in mgm^{-3}; the other pollutants are expressed in $\mu g/m^3$.

The air quality index was calculated for pollutants during pre-covid lockdown and covid lockdown to know the overall air quality index of the periods and its improvement during lockdown. Table 2 shows sub-index value of CO, NO_2, SO_2 and overall air quality index during pre-lockdown and lockdown period. A decrease of 66.31% in the overall air quality index was seen in the Kullu valley during the lockdown period.

Table 2. Sub-index of pollutant CO, NO_2, SO_2 and overall air quality during pre-COVID-19 lockdown (1 January–24 March) and during COVID-19 lockdown (25 March–31 May) for the year 2020.

Pollutant	**Time Period**	**Average**	**AQI**	**AQI Category**
CO	Pre COVID-19 Lockdown (1 January–24 March 2020)	8 h average	47.5	**Good**
	During COVID-19 Lockdown (25 March–31 May 2020)	8 h average	16.0	**Good**
NO2	Pre COVID-19 Lockdown (1 January–24 March 2020)	24 h Average	4.6	**Good**
	During COVID-19 Lockdown (25 March–31 May 2020)	24 h Average	3.5	**Good**
SO_2	Pre COVID-19 Lockdown (1 January–24 March 2020)	24 h Average	3	**Good**
	During COVID-19 Lockdown (25 March–31 May 2020)	24 h Average	2	**Good**
Overall AQI	Pre COVID-19 Lockdown (1 January–24 March 2020)	Pre COVID-19 Lockdown (1 January–24 March 2020)	47.5	**Good**

During COVID-19 Lockdown (25 March–31 May 2020)	During COVID-19 Lockdown (25 March–31 May 2020)	16	**Good**

Although the air quality was good in pre lockdown as well as post lockdown in Kullu valley according to the air quality parameters prescribed under NAAQS. However, during the lockdown period AQI shifted to clean air (AQI-16) as compared to (AQI-47) light air pollution during pre lockdown period.

5. Conclusions

The study on an ambient air quality in all the phases of the national lockdown has helped in understanding the trend of pollutants. The major findings in brief are as follows:

- There was a decrease in concentration of TSP during lockdown period (25 March 2020–31 May 2020) as compared to pre-lockdown period (1 January–24 March 2020), and also a decrease in lockdown period 2020 as co,pared to 2019 for the same period.
- Although, there was a decrease in concentration of most of the pollutants including TSP, SO_2, NO_2 and CO. The reverse trend of O3 concentration during the lockdown period was observed due to decreased particulate matter (TSP) concentrations. Reduced PM in ambient air results in increased photochemical activities and thus higher O3 production by giving way for more sunlight to pass through the atmosphere.
- A decrease of 66.31% in the overall air quality index was observed in the Kullu valley during the lockdown period. The air quality shifted from lightly polluted air to clean air during COVID-19 lockdown.

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Conflicts of Interest:

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