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# Spatiotemporal Effect of Lockdown Amid COVID-19 Pandemic on Air Quality of Kullu Valley, Northwest Himalaya, India

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**ABSTRACT**

The present study is an attempt to evaluate the effects of Lockdown due to Coronavirus Disease (COVID-19), on Air Quality Index (AQI) of Kullu valley. The Air Quality was monitoring from January 2019 to June 2019 and same time in the next year during COVID-19 period from January 2019 to June 2019 at Mohal-Kullu sampling site. $PM_{10}$ and $PM_{2.5}$ values were recorded in higher average as 80.2±3 µg $m^{-3}$ and 32.5±1 µg $m^{-3}$ respectively before the lockdown period. While lowest $PM_{10}$ and $PM_{2.5}$ concentration 8.5 µg $m^{-3}$ and 6.3 µg $m^{-3}$ respectively was recorded during lockdown period. Similarly, the AQI trend shows the Lowest Index value which is 4.2 during lockdown period in the year of 2020 and highest 25 value was observed before the lockdown period in the year of 2019. The reason behind that all the vehicular and Industrial activities were closed, the effects of which is that the 80% pollution emission has been reduced. Before the lockdown period some observations of particulate pollutants have been crossed the permissible limit (100 µg $m^{-3}$) prescribed by National Ambient Air Quality Standards (NAAQS). It is also made clear from Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model and Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) analysis that the sources of pollutants are mainly local in nature. AQI study reveals that air quality of Mohal falls under good condition but during lockdown the Air Quality was extremely good.

**Key words:** Particulate Pollutants, Gaseous Pollutants, Air Quality Index, COVID-19, Kullu Valley

## INTRODUCTION

Air pollution is one of the serious problems for human beings and the environment. Air pollution is a mixture of solid particles and gases in the air. Vehicle emissions, chemicals from factories, dust, pollen, and mold spores may be suspended as particles. Air pollution isn't only a problem outdoors; it can also be a problem within buildings, affecting your health. The presence of particle pollutants, even in tiny amounts, may have an impact on the environment by modifying the thermal characteristics of the environment. The radiative effect is shown by these gases which absorb the longwave radiation and reduce the outgoing at the Top of Atmosphere (TOA) and this leads to an increase in temperature (Wang et al. 1976). Atmospheric pollutants are released into the environment by natural and anthropogenic sources like agricultural, industrial, transportation, residential and natural sources (Barnard et al. 2001, Ramathan 2009). Air pollution not only affects the air quality but its acute and chronic effects can create various health problems in human being (Oberdorster et al. 1990). Especially, particulate matter ($PM_{2.5}$) plays foremost role in creating depression, anxiety and many other neurological problems in human being (Calderon et al. 2002, Oberdorster et al. 2004). This particulate also affects atmospheric process like reduce visibility, effect precipitation pattern and cloud formation and also play an important role in making rain, clouds and fog acidic in nature (Celis et al. 2004, Khoder 2002). Gajananda et al. (2005) monitored Total Suspended Particulate (TSP), size-separated atmospheric aerosols and Aitken Nuclei (AN) at Mohal (Kullu) and Manali tourist complex, in the northwestern part of the Himalaya from 1996 and onwards and concluded that level of air pollution is increasing over the sensitive areas of northwestern part of the Himalaya due to uncontrolled anthropogenic activities.

The Himalayan Mountain Ecosystem (HME) is one of the most vulnerable ecosystems to the climate change and so are the mountain communities, especially those mainly depend on animal husbandry, marginal agriculture and horticulture products. The HME, at present, is facing challenges created due to increasing aridity, warmer winter season, variability in precipitation, and unexpected frosts and storms (Renton 2009, Dash and Hunt 2007) which largely affect the entire range of biodiversity (Renton 2009, Kala 2013). Though the Himalayas harbours rich biodiversity and is one of the most vulnerable mountain ecosystems to climate change (Xu et al. 2009, Bawa et al. 2010), there is paucity of systematic analysis of climate change and its impacts on the Himalayan ecosystems, biodiversity and local people's livelihoods (Shrestha et al. 2012).

COVID-19 is a communicable virus that was initially identified during end of the December 2019 in the Wuhan city of China (Zhu et al. 2020). Within 2 to 3 months this virus captured the entire world (WHO, 2020). As the virus was infectious, different countries made different rules to stop the transmission of the virus like checking free public movements, social gatherings and locked hotspots of the virus. The circumstances were very critical at that time for human existence and for the economy of the world. But, at the same time worldwide quality of the air and environmental conditions were becoming better (Bao and Zhang 2020, Saadat et al. 2020, Yadav et al. 2020). The decrease in the air pollutants concentration was reported in many countries like USA, Spain, Germany, Brazil, China, Spain, Barcelona etc. (Baldasano 2020, Dantas et al. 2020, Jain and Sharma et al. 2020, Menut et al. 2020, Shakoor et al. 2020). In India, decrease in air pollutants concentration and improvement in the AQI due to less anthropogenic activities has been reported in many big cities like Kolkata, Delhi, Chennai, Hyderabad and Mumbai (Singh and Chauhan 2020) in the entire India. In Delhi, >50% decline in the $PM_{2.5}$ and $PM_{10}$ concentration was reported compared to the previous year 2019 and air quality was improved by 40 to 50 % exclusively after four days of the lockdown commencement (Garg et al. 2021, Mahato et al. 2020). Nigam et al. (2021) reported a significant decline in the concentration of the pollutants like $PM_{2.5}$, $PM_{10}$, $SO_2$ and carbon monoxide. Mishra et al. (2021) and Sathe et al. (2021) have reported a significant decrease of 30-50% in the AQI of Chandigarh, Delhi, Jaipur, Lucknow, Patna, Kolkata, Gandhinagar, Bhopal, Nashik, Mumbai, Nagpur, Hyderabad, Bengaluru, Chennai, Visakhapatnam, and Thiruvananthapuram.

The focus of this paper is to portray the effect of this lockdown on AQI and concentration of particulate matter ($PM_{2.5}$ and $PM_{10}$) in the Indian Himalayan Region (IHR) with reference to the previous year 2019. The analysis and outcomes from this study will augment the relationship between AQI and concentration of particulate matter ($PM_{2.5}$ and $PM_{10}$), that can be further utilized as patching measures for our global degrading environment.

## MATERIAL AND METHODS

### Study area

The present study area deals with ambient air quality assessment in Kullu valley. Kullu is a broad open valley formed by the Beas River between Manali and Larji. The study area forms a part of the Kullu district covering three blocks naming Naggar, Kullu, and Bhuntar (partially which lies in Beas River Valley), which is a popular tourist destination in the lower Himalayas, in Himachal Pradesh, India. This valley is famous for its temples, beauty and its majestic hills covered with Coniferous Forest and sprawling Apple Orchards. The study area comprises snow-covered valleys, glaciers, some rural settlements, and a majority of dense forest areas. The rural settlements are mostly in the vicinity of a farming area, where the month of December marks the sowing of winter crops, particularly wheat. Ambient air quality was monitored at Mohal Latitude

-31°54′54.15º N and Longitude-77°07′25.42º E. The altitude of the study area varies from 1000 m to 6000 m Above Mean Sea Level (AMSL) as shown in (Fig. 1). Average annual rainfall and temperature of the area is 733.4 mm and 17.20 p C, respectively. The climate of the study area generally remains cool and dry. This region experiences three seasons in a year, (1) cold season (October to February), (2) hot season (March to June), and (3) rainy season (July to September). Snowfall generally occurs in December and January at higher elevations due to western disturbance which approaches India from the west (Singh and Roy 2002). The average annual rainfall of the district is 1405 mm, out of which 57% occurs from June to September (CGWB 2013).

**Methods**

The present study was carried out during January to June 2019 and 2020 mainly the focus on during the lockdown period due to COVID-19. Respirable Dust Sampler (RDS; Envirotech NL-460) was used to monitor $PM_{10}$, ambient air quality was monitoring based on filtration-gravimetric method and Whatman filter paper (20.3×25.4 cm) was used. The gaseous pollutants such as $SO_2$, $NO_2$, and $NH_3$ were also monitored simultaneously in an attached Impinger with the RDS, and analyzed the same following the modified methods of West and Gaeke (1956), Jacobs and Hochheiser 1958 and Nesseler's Regeant methods, respectively. The results obtained from $PM_{10}$ concentration and gaseous pollutants were compared with NAAQS. Weighing balance (AND GR-202 make) was used for weighing filter papers. Fine Particulate Sampler (APM-550 make Envirotech) was used for $PM_{2.5}$. The Whatman Glass Micro Fibre Filter paper (GF/A (47 mm) was used to expose $PM_{2.5}$. The samples were exposed on 24 hourly bases.

The HYSPLIT model (http://www.arl.noaa.gov/HYSPLIT.php) of National Oceanic Administration (NOAA) has been used to draw 7- days backward pollution trajectories. The forward and backward Trajectories are useful in examine the role of meteorological parameters in pollutants dispersion and also describe the time scale of different chemical phenomenon (Fast and Berkowitz 1997). HYSPLIT calculation depends upon the Eulerian and Lagrangian models (Draxler et al. 1998). Eulerian model is used only to address advection and diffusion of pollutants of a fixed site where as Lagrangian model address an air parcel moving over distance (Draxler et al. 1998). The CALIOPSO satellite data has been used to get real time data of the pollutant dispersion. The Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) is the instrument used in this satellite which is designed to acquire vertical profile of atmospheric motions at two wavelengths (532 nm and 1064 nm) from near nadir viewing geometry. It also provides linear depolarization profile at 532 nm (Winker et al. 2009).

The CALIPSO satellite (launched April 2006) used to examine the role of clouds and aerosols in Earth's climate regulation. CALIPSO has a 98º orbit inclination, orbiting at 705 km and disseminating daily worldwide distribution of clouds and aerosols Yamada et al (1992). CALIPSO carries CALIOP, is an Imaging Infrared Radiometer (IIR), and a moderate spatial resolution Wide Field-of-view Camera (WFC) has depolarization corresponding to wavelength 532 nm that are proficient of discriminating amongst ice and water clouds and identifying non-spherical aerosol particles. As a result of this benefit, CALIOP is favored to quantify the vertical structure of dust plumes directly. Here, we used CALIPSO to supplement observations of aerosol acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data products.

The Aerosol Radiative Forcing (ARF) calculation equation. 1 was developed by Kim et al. (2005) as follows:

$$F= - S/4\ T{+}T{-}\ (1\text{-}N)\ 2\iota\ [(1-\alpha)\ 2\beta\omega - 2\alpha\,(1-\omega)] \quad .... (1)$$

where F is the radiative forcing (W/m$^2$), S incident solar flux at TOA, $T+$ and $T-$ are the upward and downward transmissions, N cloudiness index, $\iota$ aerosol optical depth (AOD), $\alpha$ albedo (surface), $\beta$ radiation scattered as fraction upwards, and $\omega$ is the single albedo aerosol scattering.

Air mass trajectory over the entire Kullu valley was analyzed using a HYSPLIT model. The air parcel travels the distance above the boundary layer. The boundary layer played an essential role in carrying the aerosol over a long distance. These features are explained by HYSPLIT back-trajectories connected with CALIPSO satellite observations in the events

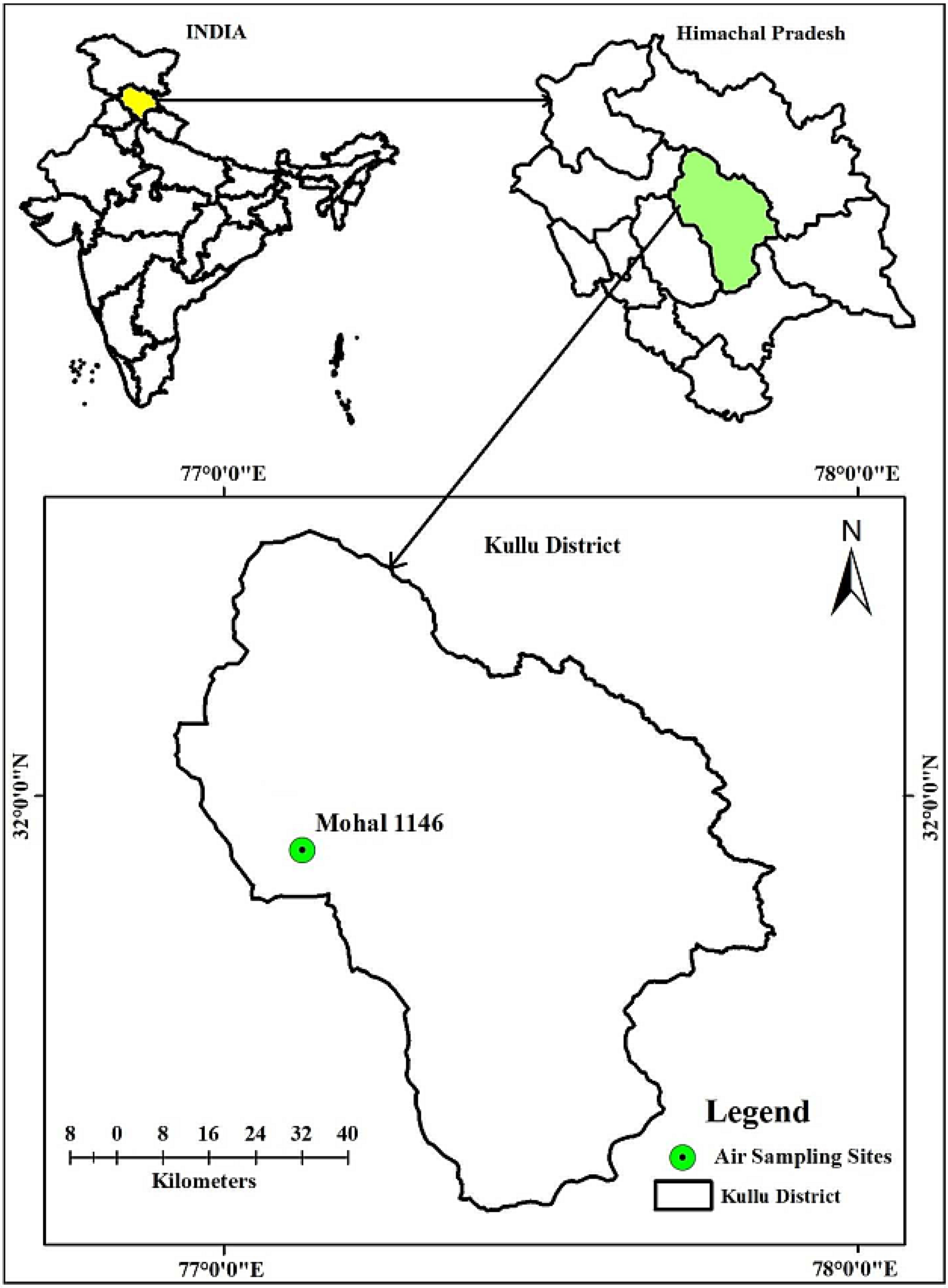


Figure 1. Location of the study area in the Kullu valley, Himachal Pradesh

of dust aerosol loading in day time. The air parcels suggest the western flow of air-born particles towards India.

### Air Quality Index (AQI)

AQI was also computed to know the overall pollution status. The AQI was measured modifying the formula used by Bhaskar and Mehta (2010) as follows equation. 2:

$$AQI = \left( \frac{M_{obs}}{M_{std}} \right) \times 100 \quad ............(2)$$

where, $M_{obs}$= observed value of air pollutants, $M_{std}$= standard value of permissible limit of NAAQS

## RESULTS AND DISCUSSION

### Air Quality Index (AQI)

The AQI is one of the most important tools which is used to report the overall air quality status and trends based on specific standards. This Index gives an idea about the environmental status as air quality and also tells the general public to understand how clear or pollute air they breathe daily. According to Environmental Protection Agency (EPA), it is divided in six different limits (Table 1).

Table 1. AQI values and level of health concerns

| Sr. No. | AQI Value | Level of health concern |
|---|---|---|
| 1 | 0-50 | Good |
| 2 | 50-100 | Moderate |
| 3 | 101-150 | Unhealthy for Sensitive Group |
| 4 | 151-200 | Unhealthy |
| 5 | 200-300 | Very Unhealthy |
| 6 | 301-500 | Hazardous |

### Local and External Sources Contribution of Pollutants

The Concentration-Weighted Trajectory (CWT) drawn in the months of April and May 2020 during the COVID-19 lockdown period for the study site of Mohal-Kullu showed that there was about 1-5 µg $m^{-3}$ contribution of particulate pollutants ($PM_{10}$) from outside and there was about 1-3 µg $m^{-3}$ contribution of particulate pollutants ($PM_{2.5}$) from outside the country. On the other side, there is a major contribution of particulate (>10 µg $m^{-3}$) matter from the immediate local area of the project affected sites shown in (Fig. 2).

It is clear from Figure 3 and Table 1, the values of AQI are in the good range for sampling sites which are under good category. The AQI shows that there is a change in index values before and during lockdown period. Before lockdown the highest AQI value was 25.0 and minimum 4.2 has been recorded. On the other side, due to COVID-19 when the lockdown was implemented, the AQI comes down a lot, during at present the highest AQI value was 12.5.

### $PM_{10}$ & $PM_{2.5}$ Concentration Before Lockdown

Before lockdown the highest ever concentration of $PM_{10}$ (162.6 µg $m^{-3}$) was observed on 16th January, 2019 shown in Figure 4. The value of $PM_{10}$ was recorded minimum 35.4 µg $m^{-3}$ on 20th May, 2019. The average concentration of $PM_{10}$ was observed 80.2±3.5 µg $m^{-3}$. The concentration of $PM_{10}$ during March to May was observed 112.3 µg $m^{-3}$ as maximum on 22nd April, 2019. On the other side, before lockdown the highest $PM_{2.5}$ concentration was recorded (65.2 µg $m^{-3}$) on 28th May 2019 and lowest concentration of $PM_{2.5}$ (4.7 µg $m^{-3}$) was observed on 28th January, 2019, and average concentration of $PM_{2.5}$ was observed 32.5±1.9 µg $m^{-3}$. During our observation period from January, 2019 to June, 2019 it was found that the total fifteen samples were cross over the beyond permissible limit (100 µg $m^{-3}$), prescribed by National Ambient Air Quality Standards (NAAQS), the reason behind that biomass burning were high during winter and increase in vehicular activities due to tourist influx as well as the developmental activities Sharma et al. (2014).

### $PM_{10}$ & $PM_{2.5}$ Concentration During Lockdown

Due to COVID-19 pandemic Government of India has declared the Lockdown from 24th March, 2020 to 31st of May, 2020. During this period the $PM_{10}$ concentration ranged between 8.5 µg $m^{-3}$ to 35.2 µg $m^{-3}$ with the mean value of 16.2.9±2.7 µg $m^{-3}$. The highest ever concentration of $PM_{10}$ (35.5 µg $m^{-3}$) was observed on 27th May, 2020 and lowest on 26th April, 2020 shown in Figure 5. The lowest concentration of $PM_{2.5}$ was observed as 6.3 µg $m^{-3}$ while the highest concentration 40.6 was observed.

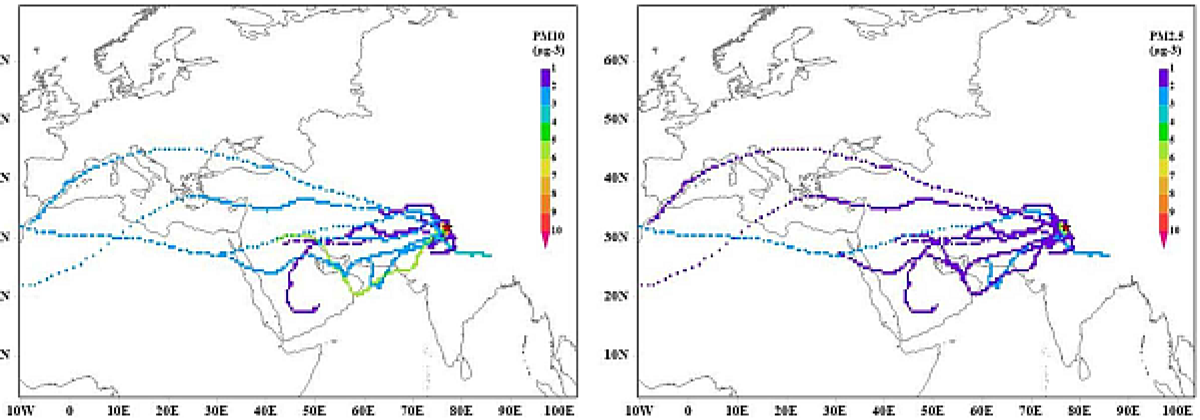

Figure 2. Concentration-Weighted Trajectory shows the sources contribution of pollutants

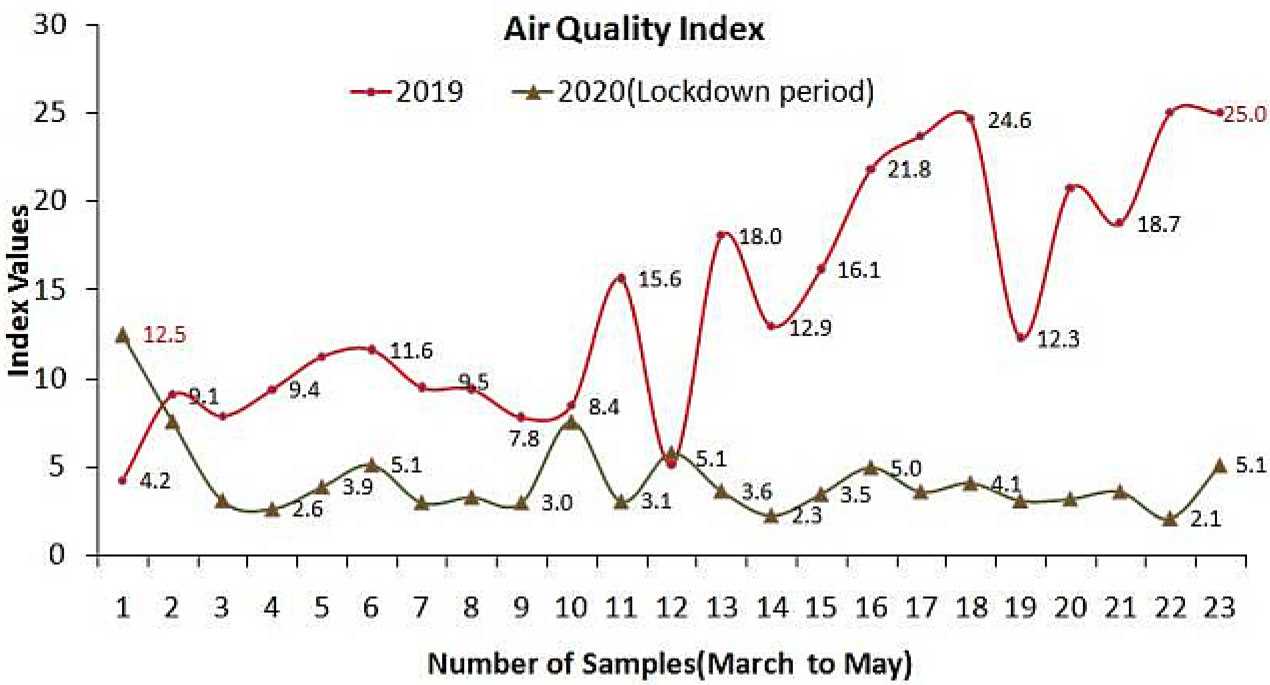


Figure 3. Air Quality Index (AQI) in study site Before and During Lockdown

**Diurnal Variation in $PM_{10}$ and $PM_{2.5}$ Concentration**

The diurnal variation of ambient air quality under observation showed that there was a change in $PM_{10}$ concentration in different time periods of a day and night. It was observed that concentration of $PM_{10}$ and $PM_{2.5}$ was highest 24.1±6 µg $m^{-3}$ 17.7± µg $m^{-3}$ respectively from 8:00 AM to 4:00 PM (Indian Standard Time (IST), local time). The reason for this is that even during lockdown the essential departmental vehicular activity has been continued. On the other side, the lowest concentration was observed from 04:00 AM to 12:00 AM (IST local time), shown in Figure 6 and Annexure. 6.

**Percent (%) Change in $PM_{10}$ Pollutants During Lockdown Period**

The central government also announced the curfew in the state of Himachal Pradesh due to COVID-19 epidemic. All the vehicular and Industrial activities were closed, which has a positive impact on our environment as well as ecosystem services. In which we wanted to know how many % reduction in air pollution. During the study it has been found that there is an 80% reduction in air pollution shown in Annexure. 1.

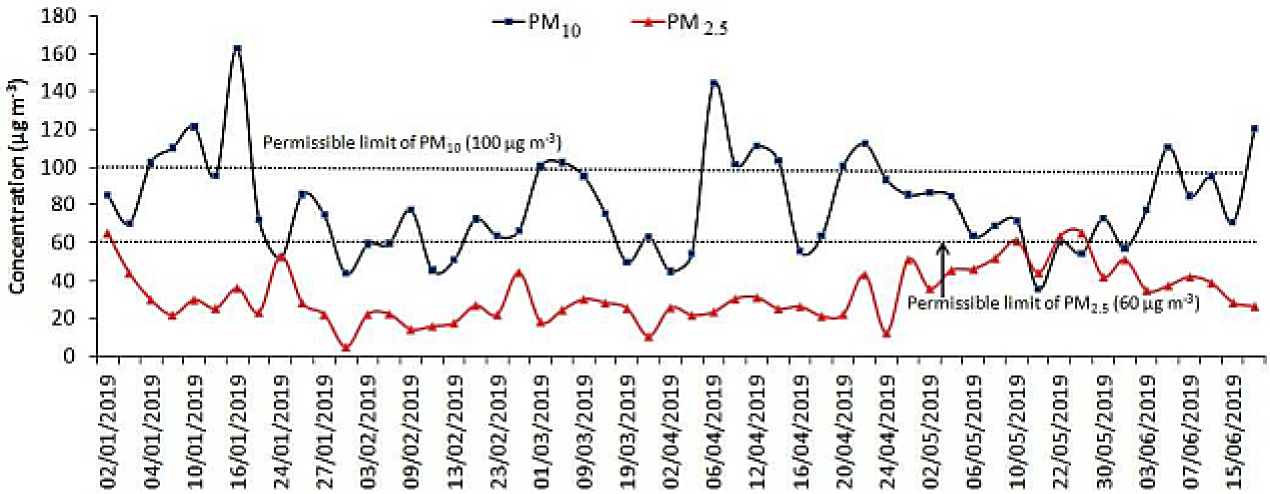


Figure 4. $PM_{10}$ and $PM_{2.5}$ Concentration at Mohal in 2019

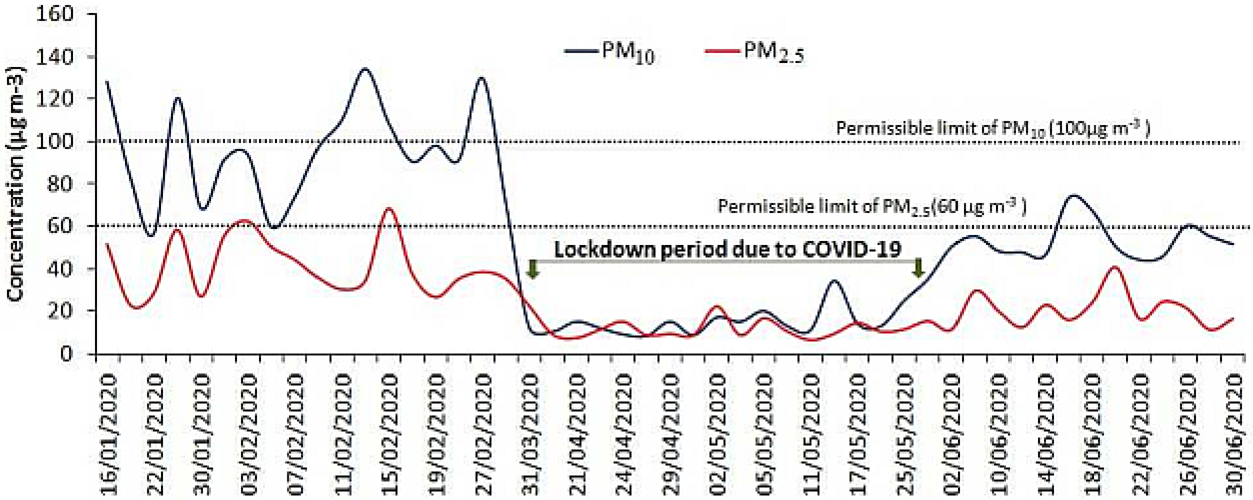


Figure 5. $PM_{10}$ Concentration during COVID-19 epidemic

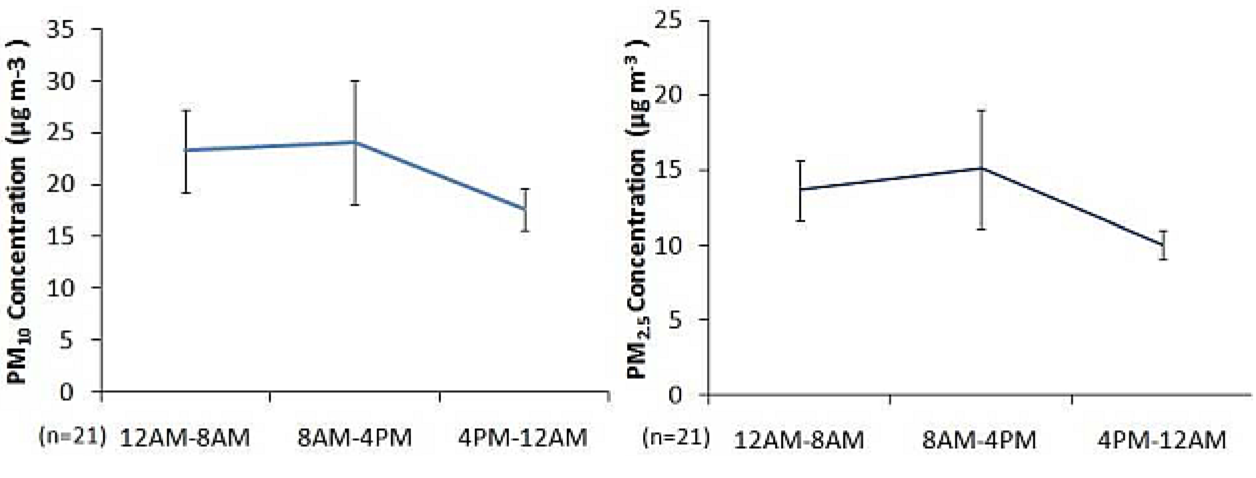


Figure 6. Diurnal concentration of $PM_{10}$ and $PM_{2.5}$

**Gaseous Pollutants During January 2019 to June 2020**

The level of $NO_2$ was observed to be ranged between 1.5 µg $m^{-3}$ to 6.3 µg $m^{-3}$ with the mean value of 3.7±0.1 µg $m^{-3}$. While $SO_2$ concentration ranged from 0.1 µg $m^{-3}$ to 2.1 µg $m^{-3}$ with the mean concentration of 1.0±0.05 µg $m^{-3}$. On the other side, the $NH_3$ concentration ranged between 4.1 µg $m^{-3}$ to 32.1 µg $m^{-3}$ shown in Figure 7 and Annexures 2, 4. All the values were within the permissible limit.

**Gaseous Pollutants Concentration During COVID-19**

The study reveals that the gaseous pollutants such as $NO_2$, $SO_2$ and $NH_3$ were lowest as comparison to previous year 2019. The $NO_2$ concentration ranged between 0.3 µg $m^{-3}$ to 9.3 µg $m^{-3}$ with the mean value of 2.7 ±0.2 µg $m^{-3}$. While the $SO_2$ concentration ranged from 0.1 µg $m^{-3}$ to 1.9 µg $m^{-3}$ with the mean values of 0.8± 0.06 µg $m^{-3}$ were recorded. All the values were well within the permissible limit shown in Figure 8 and Annexure 3, 5.

**Back Trajectories, CALIPSO and Pollution Sources**

The seven days back trajectories were drawn using HYSPLIT from NOAA to indicate long range transport source during pollution episodes. The trajectories were drawn one episode's value during winter season i.e., 16th January, 2019 at Mohal and during spring season episode value on 10th April, 2019 at Mohal during the occasion of high pollution days.

In and around Mohal site, the highest concentration of particulate pollutants value (162.6 µg $m^{-3}$) was observed on 16th January, 2019 when the back trajectory was coming from Morocco, Homoda Desert. The trajectory, thereafter, passed through Algeria, Libya near Sahara Desert, Iraq, Afghanistan, Islamabad (Pakistan), Pathankot (India), Kangra district of Himachal Pradesh (India) and ultimately reached at Mohal shown in Figure 9a. At the same time, observation through CALIPSO shown that the vertical distribution of dust aerosols was mainly below 8 km at Tibetan Plateau and Irkustsk (Russia) shown in Figure 10a. It is thus made clear that all these observations through the trajectories have shown that they did not pass through the Tibetan Plateau and Irkustsk (Russia) region and were not contributing directly to pollution episodes. This indicates that these episodes caused due to local pollutants.

During spring season, the CALIPSO image shown in Figure 10 that the vertical distribution of dust aerosols at Koppal district of Karnataka (India). The back trajectory moved from the Western Sahara, Algeria, Lebia and passed through Iran, Afganistan Pakistan, Kangra (India) and ultimately reached at Mohal shown in Figure 9b. But the trajectories did not cross over the vertical distribution of smoke, aerosols. These observations showed that there was no any outer source contributing to particulate pollution at Mohal shown in Figure 10.

There are various studies that shows that Himalayan ecosystem is not untouched by anthropogenic activities (biomass burning, forest fire, vehicular emission etc.) and these activities leads to increase in the air pollution (Gajananda et al. 2005). It has been reported previously that sources of air pollution in the sites Kothi, Mohal (Western Himalayan) and Darjeeling (Eastern Himalayan) are human interferences like biomass burning, vehicular emission and long-range transport of the pollutants (Chatterjee et al. 2010, Kuniyal et al. 2015). Similarly, it has been observed in the current study that the sources of the pollution in Mohal are local as well as long range transported dust particles as depicted by HYSPLIT model. Kumar et al. (2020) also reported in his study that industrial activities in the Himalayan region, vehicular emission and long-range transport of the pollutants are liable for the degradation of the air quality of the Himalayan region. Sharma et al. (2014) disclosed that in Himalayan region quality of the air mainly affected by the native activities like biomass burning, tourism, agriculture and transport.

Further in the present study, it has been concluded that during lockdown the concentration of $PM_{2.5}$ and $PM_{10}$ has been decreased whereas, the AQI also improved such as the values reached at 2.6 shown in Annexure 5. Mahato et al. (2020) have reported the same in his study that in megacity Delhi the particulate pollutants like $PM_{2.5}$ and $PM_{10}$ were reduced to (~40-60%). Yadav et al. (2020) and Mor et al. (2021) also revealed during 2018 similar trend in the other major cities of India like Chandigarh, Mumbai, Pune and Ahmadabad. This decreasing trend of pollutants during lockdown period was

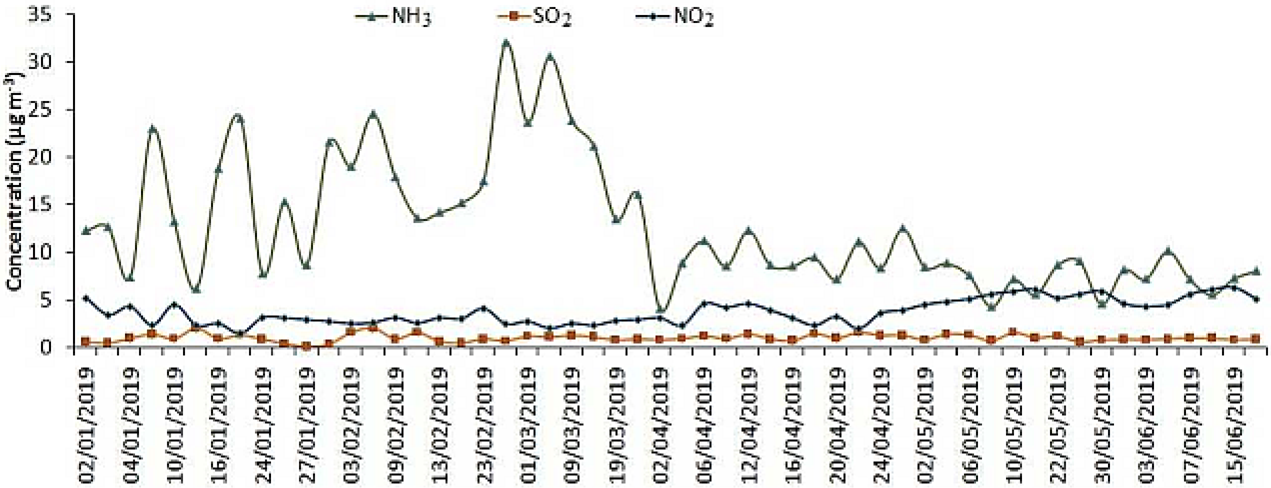


Figure 7. The gaseous concentration in the study site

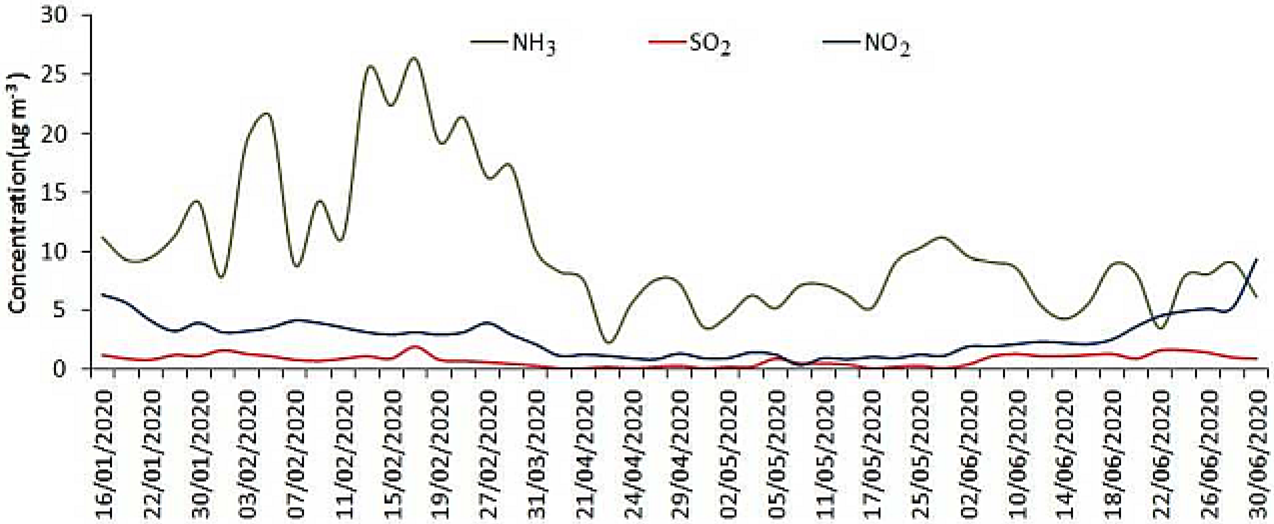


Figure 8. The concentration of gaseous pollutants in the study site

observed, due to lesser human interferences with environment (Beig et al. 2020). The considerable decline in the pollutant's concentration can be accredited to the lesser vehicular emission and industrial activities (Biswal et al. 2020; Singh et al. 2020; Tobias et al. 2020). Therefore, on the basis of this study it has been disclosed that during lockdown anthropogenic activities like vehicular emission, tourism, industrial activities were minimum. All the respective studies and in this current study AQI was improved during the lockdown period. Yet, overall impacts over this period were temporary it is important to implement air pollution mitigation strategies to protect nature and human health associated with air pollution.

This study significantly directs us toward the acute relationship between particulate matter and routine mankind activities. As from the above results we can easily analyze the proportional decrease in the concentration of $PM_{2.5}$ and $PM_{10}$ with the decrease in human activities during lockdown. The monitoring of the air pollutants is crucial as to balance the Himalayan ecosystem in a subtle way and its investigation also concentrates on curving the ill effects on human health. So, it is very much necessary to maintain the balance between commercial activities (industries, tourism, agriculture etc.) and environment.

## CONCLUSION

In essence, particulate pollution is high before lockdown period which cross the permissible limit (100 µg m$^{-3}$) as set by NAAQS. Because during this

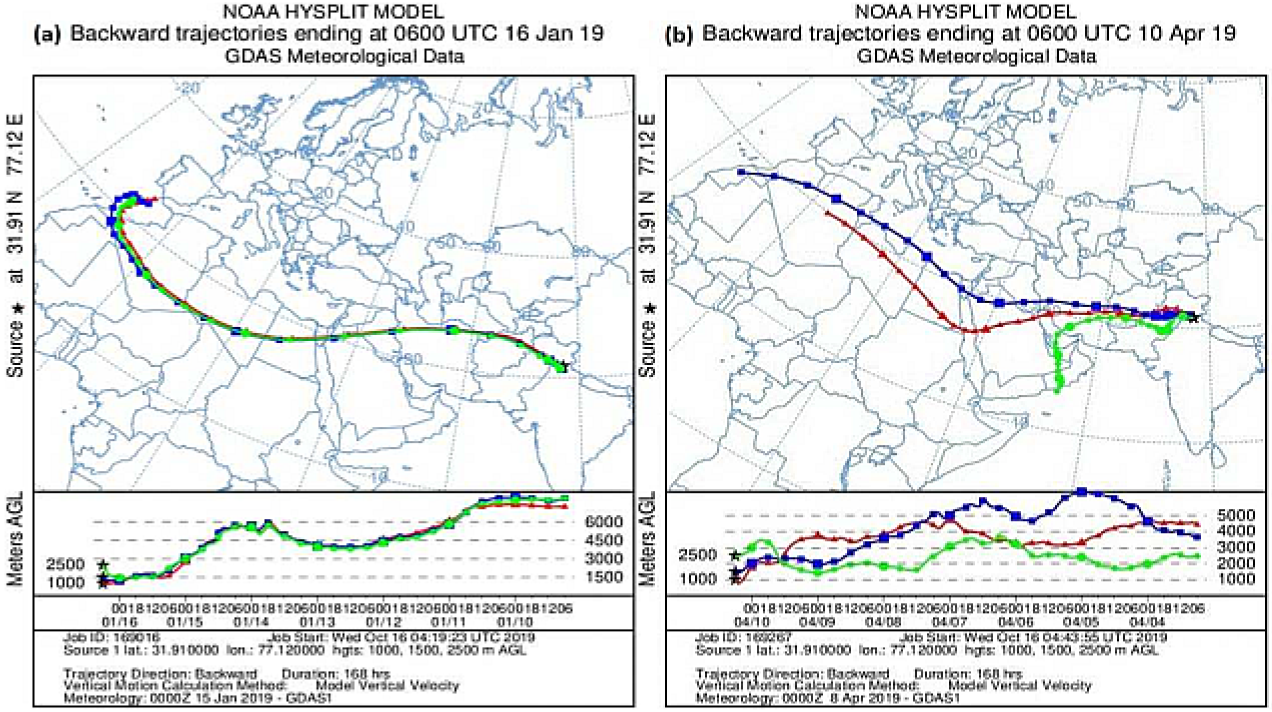


Figure 9. Back trajectories using HYSPLIT Model to relate with highest particulate pollutants for: (a) Winter season (b) Spring season of before lockdown

time vehicular and industrial activity were ongoing; so here the pollutants level is highest. While Lockdown were announced due to COVID-19 at that time period it was observed that the pollution level was decreased as 80%. It is also made clear from HYSPLIT, CALIPSO and CWT analysis that there is local source of pollutants. The AQI study reveals that air quality of Mohal falls under good condition and during Lockdown the AQI were much better than other days. Therefore, on the basis of this study it reveals that these types of Lockdowns are lifelines for our environment.

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**Authors' contributions:** All authors contributed equally

**Conflict of interest:** Authors declare no conflict of interest

## REFERENCES

Baldasano, J.M. 2020. COVID-19 lockdown effects on air quality by $NO_2$ in the cities of Barcelona and Madrid (Spain). Science of the Total Environment, 741, 140353.

Bao, R. and Zhang, A. 2020. Does lockdown reduce air pollution Evidence from 44 cities in northern China. Science of the Total Environment, 731, 139052.

Basannagari, B. and Kala, C.P. 2013. Climate Change and Apple Farming in Indian Himalayas: A Study of Local Perceptions and Responses. PLOS ONE, 8(10), e77976.

Bawa, K.S., Koh, L.P., Lee, T.M., Liu, J. and Ramakrishnan, P. 2010. China, India, and the Environment. Science, 327, 1457–1459.

Beig, G., Sahu, S.K., Singh, V., Tikle, S., Sobhana, S.B., Gargeva, P. and Murthy, B.S. 2020. Objective evaluation of stubble emission of North India and quantifying its impact on air quality of Delhi. Science of The Total Environment, 709, 36126.

Bernard, S.M., Samet, J.M., Grambsch, A., Ebi, K.L. and Romieu, I. 2001. The potential impacts of climate variability and change on air pollution-related health effects in the United States. Environmental Health Perspectives, 109(2), 199.

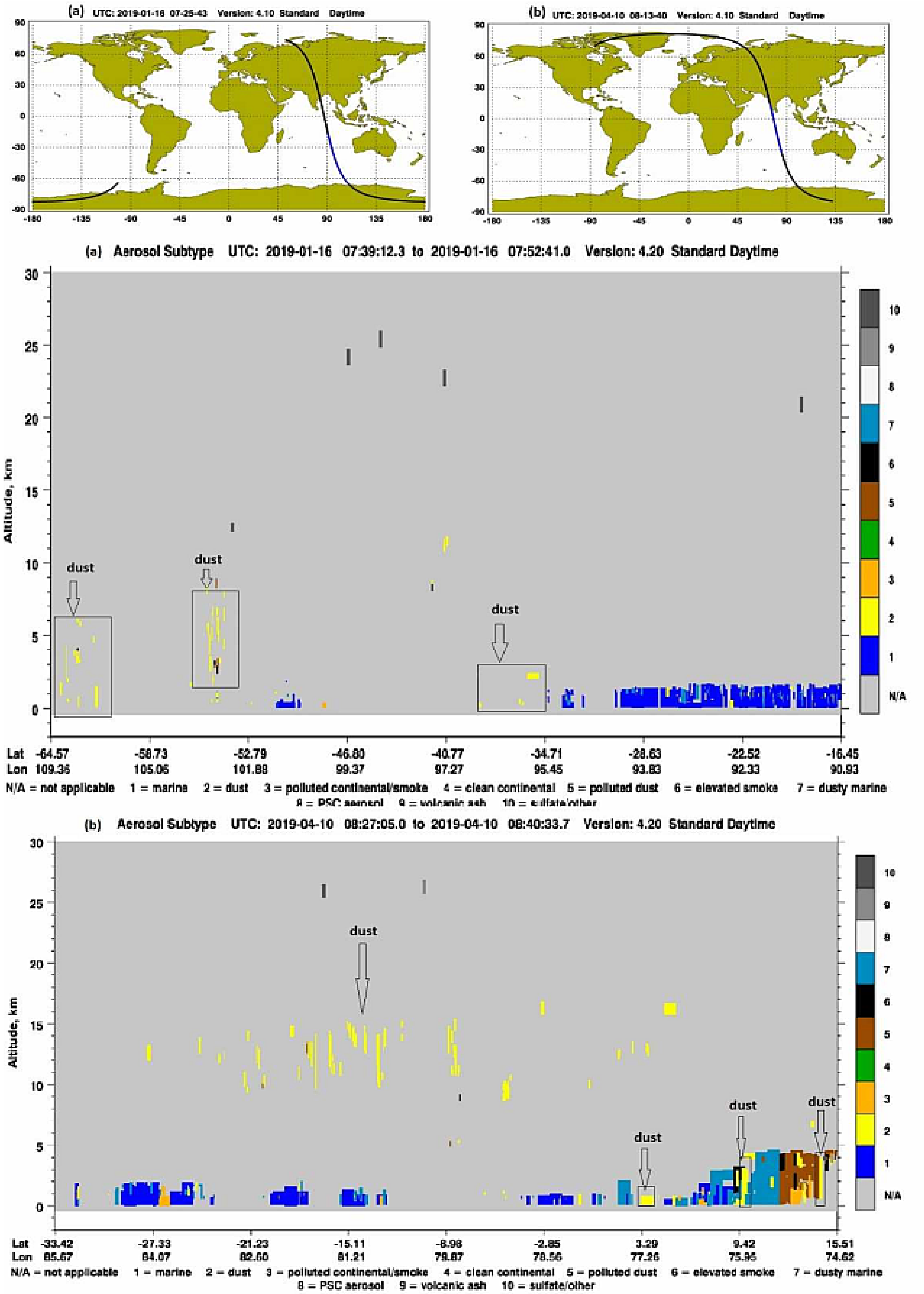


Figure 10. CALIPSO Model to relate with highest particulate pollutants during winter and spring season of Before Lockdown

Bhaskar, B.V. and Mehta, V.M. 2010. Atmospheric particulate pollutants and their relationship with meteorology in Ahmedabad. Aerosol and Air Quality Research, 10, 301-315.

Biswal, A., Singh, T., Singh, V., Ravindra, K. and Mor, S. 2020. COVID-19 lockdown and its impact on tropospheric NO2 concentrations over India using satellite-based data. Heliyon, 6(9), 04764.

Calderon-Garcidueñas, L. Azzarelli, B., Acuna, H., Garcia, R., Gambling, T.M. Osnaya, N. and Rewcastle, B. 2002. Air pollution and brain damage. Toxicologic Pathology, 30 (3), 373-389.

Celis, J.E., Morales, J.R., Zaror, C.A. and Inzunza, J.C. 2004. A study of the particulate matter $PM_{10}$ composition in the atmosphere of Chillan, Chile. Chemosphere, 54, 541– 550.

Central Ground Water Board (CGWB). 2013. Groundwater Information Booklet Kullu district Himachal Pradesh. Ministry of Water Resources, Government of India.

Chatterjee, A., Adak, A., Singh, A.K., Srivastava, M.K., Ghosh, S.K., Tiwari, S., Devara, P.C.S. and Raha, S. 2010. Aerosol chemistry over a high-altitude station at northeastern Himalayas, India. PLoS One, 5, e11122.

Dantas, G., Siciliano, B., França, B.B., da Silva, C.M. and Arbilla, G. 2020. The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil. Science of the Total Environment, 729, 139085.

Dash S.K. and Hunt J.C.R. 2007. Variability of climate change in India. Current Science, 93, 782–788.

Draxler, R.R. and Hess, G.D. 1999. An overview of the HYSPLIT-4 modelling system for trajectories, dispersion, and deposition. Australian Meteorological Magazine, 47, 295-308.

Fast J.D. and Berkowitz C.M. 1997. Evaluation of back trajectories associated with ozone transport during the 1993 North Atlantic Regional Experiment. Atmospheric Environment, 31(6), 825-837.

Gajananda, K., Kuniyal, J.C., Momin, G.A., Rao, P.S.P., Safai, P.D., Tiwari, S. and Ali, K. 2005. Trend of atmospheric aerosols over the north-western Himalayan region, India. Atmospheric Environment, 39(27), 4817-4825.

Garg, A., Kumar, A. and Gupta, N. C. 2021. Comprehensive study on impact assessment of lockdown on overall ambient air quality amid COVID-19 in Delhi and its NCR, India. Journal of Hazardous Materials Letters, 2, 100010.

Jain, S. and Sharma, T. 2020. Social and travel lockdown impact considering coronavirus disease (COVID-19) on air quality in megacities of India: present benefits, future challenges and way forward. Aerosol and Air Quality Research, 20(6), 1222-1236.

Jocobs, M.B, and Hochheiser, S. 1958 Continuous sampling and ultra micro determination of nitrogen oxide in air analyst. Chemistry, 30, 426-428.

Kala, C.P. 2007. Local preferences of ethnobotanical species in the Indian Himalaya: Implications for environmental conservation. Current Science, 93, 1828–1834.

Kala, C.P. 2013. Climate change and challenges of biodiversity conservation. Pp. 259-269. In: Kala, C.P. and Silori, C.S. (Eds.) Biodiversity, Communities and Climate Change. New Delhi: The Energy and Resources Institute.

Khoder, M.I. 2002. Atmospheric conversion of sulfur dioxide to particulate sulfate and nitrogen dioxide to particulate nitrate and gaseous nitric acid in an urban area. Chemosphere, 49(6), 675-684.

Kim, S.W., Yoon, S.C., Jefferson, A., Ogren, J.A., Dutton, E.G., Won, J.G. and Han, J.S. 2005. Aerosol optical, chemical and physical properties at Gosan, Korea during Asian dust and pollution episodes in 2001. Atmospheric Environment, 39(1), 39-50.

Kumar, R., Lee, J.H., Shie, R.H., Chio, C.P. and Chan, C.C., 2020. Patterns and sources of PM10 in the ecologically sensitive Himalayan Region in Himachal Pradesh, India. Aerosol and Air Quality Research, 20(3), 410-418.

Kuniyal, J.C., Sharma, M., Chand, K. and Mathela, C.S. 2015. Water soluble ionic components in particulate matter (PM10) during high pollution episode days at Mohal and Kothi in the North-Western Himalaya, India. Aerosol and Air Quality Research, 15(2), 529-543.

Mahato, S., Pal, S. and Ghosh, K.G. 2020. Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. Science of the Total Environment, 730, 139086.

Menut, L., Bessagnet, B., Siour, G., Mailler, S., Pennel, R. and Cholakian, A. 2020. Impact of lockdown measures to combat Covid-19 on air quality over western Europe. Science of the Total Environment, 741, 140426.

Mishra, A.K., Rajput, P., Singh, A., Singh, C.K. and Mall, R.K. 2021. Effect of lockdown amid COVID-19 on ambient air quality in 16 Indian cities. Frontiers in Sustainable Cities, ??, 101.

Mor, S., Kumar, S., Singh, T., Dogra, S., Pandey, V. and Ravindra, K. 2021. Impact of COVID-19 lockdown on air quality in Chandigarh, India: understanding the emission sources during controlled anthropogenic activities. Chemosphere, 263, 127978.

Nigam, R., Pandya, K., Luis, A.J., Sengupta, R. and Kotha, M. 2021. Positive effects of COVID-19 lockdown on air quality of industrial cities (Ankleshwar and Vapi) of Western India. Scientific reports, 11(1), 1-12.

Oberdörster, G., Sharp, Z., Atudorei, V., Elder, A., Gelein, R., Kreyling, W. and Cox, C. 2004. Translocation of inhaled ultrafine particles to the brain. Inhalation Toxicology, 16(6-7), 437-445.

Ramanathan, V. and Feng, Y. 2009. Air pollution, greenhouse gases and climate change: Global and regional perspectives. Atmospheric Environment, 43(1), 37-50.

Renton, A. 2009. Suffering the Science: Climate Change, People and Poverty (Vol. 130). Oxfam.

Saadat, S., Rawtani, D. and Hussain, C.M. 2020. Environmental perspective of COVID-19. Science of the Total Environment, 728, 138870.

Sathe, Y., Gupta, P., Bawase, M., Lamsal, L., Patadia, F. and Thipse, S. 2021. Surface and satellite observations of air pollution in India during COVID-19 lockdown: Implication to air quality. Sustainable Cities and Society, 66, 102688.

Shakoor, A., Chen, X., Farooq, T.H., Shahzad, U., Ashraf, F., Rehman, A. and Yan, W. 2020. Fluctuations in environmental pollutants and air quality during the lockdown in the USA and China: two sides of COVID-19 pandemic. Air Quality, Atmosphere & Health, 13(11), 1335-1342.

Sharma, S.K., Mandal, T.K., Sharma, C., Kuniyal, J.C., Joshi, R., Dhyani, P.P., Sen, A., Ghayas, H., Gupta, N.C., Sharma, P. and Saxena, M. 2014. Measurements of particulate (PM2. 5), BC and trace gases over the northwestern Himalayan region of India. Mapan, 29(4), 243-253.

Shrestha, U.B., Gautam, S. and Bawa, K.S. 2012. Widespread climate change in the Himalayas and associated changes in local ecosystems. PloS one, 7(5), e36741.

Singh, R.B. and Sen Roy, S. 2002. Climate variability and hydrological extremes in a Himalayan catchment. In: ERB and Northern European FRIEND Project 5 Conf., Slovakia.

Singh, R.P. and Chauhan, A. 2020. Impact of lockdown on air quality in India during COVID-19 pandemic. Air Quality, Atmosphere & Health, 13(8), 921-928.

Tobías, A., Carnerero, C., Reche, C., Massagué, J., Via, M., Minguillón, M.C., Alastuey, A. and Querol, X. 2020. Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic. Science of the Total Environment, 726, 138540.

Wang, W.C., Yung, Y.L., Lacis, A.A., Mo, T.A. and Hansen, J.E. 1976. Greenhouse Effects due to Man-Made Perturbations of Trace Gases: Anthropogenic gases may alter our climate by plugging an atmospheric window for escaping thermal radiation. Science, 194(4266), 685-690.

West, P.W. and Gaeke, G.C. 1956. Fixation of sulfur dioxide as disulfitomercurate (II) and subsequent colorimetric estimation. Analytical Chemistry, 28(12), 1816-1819.

Winker, D.M., Vaughan, M.A., Omar, A., Hu, Y., Powell, K.A., Liu, Z., Hunt, W.H. and Young, S.A. 2009. Overview of the CALIPSO mission and CALIOP data processing algorithms. Journal of Atmospheric and Oceanic Technology, 26(11), 2310-2323.

World Health Organization (WHO). 2020. Rolling Updates on Coronavirus Disease (COVID-19). Retrieved from. https://www.who.int/emergencies/diseases/novel coronavirus-2019/events.

Xu, J., Grumbine, R.E., Shrestha, A., Eriksson, M., Yang, X., Wang, Y.U.N. and Wilkes, A. 2009. The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods. Conservation Biology, 23(3), 520-530.

Yadav, R., Korhale, N., Anand, V., Rathod, A., Bano, S., Shinde, R., Latha, R., Sahu, S.K., Murthy, B.S. and Beig, G. 2020. COVID-19 lockdown and air quality of SAFAR-India metro cities. Urban Climate, 34, 100729.

Yamada, T., Shiraiwa, T., Iida, H., Kadota, T. and Watanabe, T. 1992. Fluctuations of the glaciers from the 1970s to 1989 in the Khumbu, Shorong and Langtang regions, Nepal Himalayas. Bulletin of Glacier Research, (10), 11-19.

Zhu, N., Zhang, D., Wang, W., Li, X., Yang, B., Song, J., Zhao, X., Huang, B., Shi, W., Lu, R., Niu, P., Zhan, F., Ma, X, Wang, D., Xu, W., Wu, G., Gao, G.F. and Tan, W. 2020. A novel coronavirus from patients with pneumonia in China, 2019. New England Journal of Medicine, 382, 727-733.

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Annexure 1. Change (%) in particulate pollution before lockdown (19 March to 30 May 2019)

| Number of Samples | PM $_{10}$ (µg m$^{-3}$) 2019 | 2020 | % Change in Pollutants |
|---|---|---|---|
| 1 | 62.8 | 12.3 | |
| 2 | 44.8 | 10.6 | |
| 3 | 54.2 | 15.3 | |
| 4 | 144.3 | 12.3 | |
| 5 | 101.3 | 9.3 | |
| 6 | 111.2 | 8.5 | |
| 7 | 103.2 | 15.3 | |
| 8 | 55.6 | 8.9 | |
| 9 | 63.2 | 17.3 | |
| 10 | 100.3 | 15.2 | |
| 11 | 112.3 | 20.3 | |
| 12 | 93.2 | 13.2 | |
| 13 | 85.2 | 11.3 | |
| 14 | 86.3 | 34.5 | |
| 15 | 84.2 | 14.3 | |
| 16 | 63.2 | 13.2 | |
| 17 | 68.7 | 25.3 | |
| 18 | 71.4 | 35.2 | |
| Average $PM_{10}$ | 83.6 | 16.2 | -80.06 |
| Average $PM_{2.5}$ | 32.5 | 15.3 | -63.07 |

Annexure 2. Gaseous and particulate pollutants and Air Quality Index (AQI) from January to March 2019

| Sampling date | $NH_3$ | $SO_2$ | $NO_2$ | $PM_{10}$ | $PM_{2.5}$ | AQI |
|---|---|---|---|---|---|---|
| **01/01/2019** | 12.3 | 0.6 | 5.2 | 85.1 | 65.1 | 22.7 |
| **02/01/2019** | 12.7 | 0.5 | 3.4 | 70.1 | 44.2 | 15.5 |
| **04/01/2019** | 7.4 | 1.0 | 4.3 | 102.3 | 30.0 | 11.1 |
| **08/01/2019** | 23.0 | 1.4 | 2.3 | 110.1 | 21.8 | 8.5 |
| **10/01/2019** | 13.2 | 0.9 | 4.5 | 121.3 | 29.9 | 11.3 |
| **14/01/2019** | 6.2 | 2.1 | 2.3 | 95.3 | 25.3 | 9.5 |
| **16/01/2019** | 18.8 | 0.9 | 2.5 | 162.6 | 36.1 | 13.7 |
| **18/01/2019** | 24.1 | 1.3 | 1.5 | 72.0 | 23.2 | 8.6 |
| **24/01/2019** | 7.8 | 0.9 | 3.1 | 51.8 | 53.3 | 18.4 |
| **26/01/2019** | 15.3 | 0.4 | 3.1 | 85.3 | 28.3 | 10.4 |
| **27/01/2019** | 8.7 | 0.1 | 2.9 | 74.3 | 22.1 | 8.2 |
| **28/01/2019** | 21.6 | 0.3 | 2.7 | 43.6 | 4.7 | 2.1 |
| **03/02/2019** | 19.0 | 1.6 | 2.5 | 59.2 | 22.1 | 8.1 |
| **05/02/2019** | 24.6 | 2.1 | 2.6 | 59.4 | 22.3 | 8.1 |
| **09/02/2019** | 17.9 | 0.9 | 3.1 | 77.3 | 14.2 | 5.6 |
| **11/02/2019** | 13.6 | 1.6 | 2.6 | 45.4 | 15.8 | 5.8 |
| **13/02/2019** | 14.2 | 0.6 | 3.1 | 50.8 | 17.5 | 6.4 |
| **17/02/2019** | 15.2 | 0.4 | 3.0 | 72.3 | 26.9 | 9.8 |
| **23/02/2019** | 17.5 | 0.9 | 4.1 | 63.2 | 22.0 | 8.1 |
| **25/02/2019** | 32.1 | 0.7 | 2.5 | 66.2 | 44.5 | 15.6 |
| **01/03/2019** | 23.7 | 1.2 | 2.7 | 100.3 | 18.2 | 7.2 |
| **07/03/2019** | 30.7 | 1.1 | 2.0 | 102.3 | 24.5 | 9.3 |
| **09/03/2019** | 23.9 | 1.3 | 2.5 | 95.1 | 30.2 | 11.1 |
| **15/03/2019** | 21.2 | 1.1 | 2.3 | 75.1 | 28.3 | 10.3 |
| **19/03/2019** | 13.5 | 0.8 | 2.8 | 49.8 | 25.3 | 9.0 |

Annexure 3. Gaseous and particulate pollutants and Air Quality Index (AQI) from April to June 2019

| Sampling date | $NH_3$ | $SO_2$ | $NO_2$ | $PM_{10}$ | $PM_{2.5}$ | AQI |
|---|---|---|---|---|---|---|
| **02/04/2019** | 4.1 | 0.8 | 3.1 | 44.8 | 25.6 | 9.1 |
| **04/04/2019** | 8.9 | 0.9 | 2.3 | 54.2 | 21.7 | 7.9 |
| **06/04/2019** | 11.2 | 1.2 | 4.6 | 144.3 | 23.4 | 9.4 |
| **10/04/2019** | 8.6 | 0.9 | 4.2 | 101.3 | 30.4 | 11.2 |
| **12/04/2019** | 12.3 | 1.4 | 4.6 | 111.2 | 31.2 | 11.6 |
| **14/04/2019** | 8.7 | 0.9 | 3.9 | 103.2 | 25.1 | 9.5 |
| **16/04/2019** | 8.6 | 0.7 | 3.1 | 55.6 | 26.3 | 9.4 |
| **18/04/2019** | 9.5 | 1.5 | 2.3 | 63.2 | 21.2 | 7.8 |
| **20/04/2019** | 7.2 | 1.0 | 3.2 | 100.3 | 22.1 | 8.4 |
| **22/04/2019** | 11.1 | 1.6 | 2.0 | 112.3 | 43.2 | 15.6 |
| **24/04/2019** | 8.4 | 1.3 | 3.6 | 93.2 | 12.3 | 5.1 |
| **26/04/2019** | 12.5 | 1.3 | 3.9 | 85.2 | 51.3 | 18.0 |
| **02/05/2019** | 8.5 | 0.8 | 4.5 | 86.3 | 35.9 | 12.9 |
| **04/05/2019** | 8.9 | 1.4 | 4.8 | 84.2 | 45.6 | 16.1 |
| **06/05/2019** | 7.6 | 1.3 | 5.1 | 63.2 | 46.3 | 16.2 |
| **08/05/2019** | 4.3 | 0.7 | 5.6 | 68.7 | 52.1 | 18.1 |
| **10/05/2019** | 7.2 | 1.6 | 5.9 | 71.4 | 61.1 | 21.2 |
| **20/05/2019** | 5.6 | 1.0 | 6.1 | 35.4 | 44.3 | 15.2 |
| **22/05/2019** | 8.7 | 1.2 | 5.2 | 60.0 | 63.4 | 21.8 |
| **28/05/2019** | 9.1 | 0.6 | 5.6 | 54.3 | 65.2 | 22.4 |
| **30/05/2019** | 4.6 | 0.8 | 5.9 | 72.5 | 42.1 | 14.9 |
| **01/06/2019** | 8.2 | 0.9 | 4.6 | 57.2 | 51.3 | 17.7 |
| **03/06/2019** | 7.2 | 0.8 | 4.3 | 77.3 | 34.9 | 12.5 |
| **05/06/2019** | 10.2 | 0.9 | 4.5 | 110.6 | 37.4 | 13.6 |
| **07/06/2019** | 7.2 | 1.0 | 5.6 | 84.6 | 42.1 | 15.0 |
| **09/06/2019** | 5.6 | 1.0 | 6.1 | 94.6 | 38.9 | 14.0 |
| **15/06/2019** | 7.3 | 0.8 | 6.3 | 70.6 | 28.5 | 10.3 |
| **17/06/2019** | 8.1 | 0.9 | 5.1 | 120.3 | 26.5 | 10.1 |

Annexure 4. Gaseous and particulate pollutants and Air Quality Index (AQI) from January to March 2020

| Sampling date | $NH_3$ | $SO_2$ | $NO_2$ | $PM_{10}$ | $PM_{2.5}$ | AQI |
|---|---|---|---|---|---|---|
| **16/01/2020** | 11.2 | 1.2 | 6.3 | 127.9 | 51.4 | 18.5 |
| **20/01/2020** | 9.3 | 0.9 | 5.6 | 82.8 | 22.7 | 8.5 |
| **22/01/2020** | 9.5 | 0.8 | 4.1 | 56.5 | 28.4 | 10.1 |
| **24/01/2020** | 11.3 | 1.2 | 3.2 | 120.3 | 58.2 | 20.7 |
| **30/01/2020** | 14.2 | 1.1 | 3.9 | 68.5 | 26.8 | 9.7 |
| **01/02/2020** | 7.9 | 1.6 | 3.1 | 91.1 | 55.3 | 19.4 |
| **03/02/2020** | 19.3 | 1.3 | 3.2 | 93.7 | 62.3 | 21.8 |
| **05/02/2020** | 21.3 | 1.1 | 3.5 | 59.6 | 50.3 | 17.5 |
| **07/02/2020** | 8.9 | 0.8 | 4.1 | 73.4 | 44.2 | 15.6 |
| **09/02/2020** | 14.3 | 0.7 | 3.9 | 96.8 | 35.6 | 12.9 |
| **11/02/2020** | 11.3 | 0.9 | 3.5 | 109.8 | 30.2 | 11.2 |
| **13/02/2020** | 25.3 | 1.1 | 3.1 | 134.0 | 34.3 | 12.9 |
| **15/02/2020** | 22.3 | 0.9 | 2.9 | 108.3 | 68.2 | 23.9 |
| **17/02/2020** | 26.3 | 1.9 | 3.1 | 90.2 | 37.5 | 13.5 |
| **19/02/2020** | 19.3 | 0.8 | 2.9 | 97.8 | 26.5 | 9.9 |
| **25/02/2020** | 21.3 | 0.7 | 3.1 | 91.2 | 35.2 | 12.8 |
| **27/02/2020** | 16.3 | 0.6 | 3.9 | 129.6 | 38.4 | 14.2 |
| **02/03/2020** | 17.2 | 0.4 | 2.9 | 70.4 | 35.1 | 12.5 |
| **31/03/2020** | 10.2 | 0.3 | 2.1 | 12.3 | 22.3 | 7.6 |

Annexure 5. Gaseous and Particulate pollutants and Air Quality Index (AQI) from April to June 2020

| Sampling date | $NH_3$ | $SO_2$ | $NO_2$ | $PM_{10}$ | $PM_{2.5}$ | AQI |
|---|---|---|---|---|---|---|
| **20/04/2020** | 8.3 | 0.1 | 1.1 | 10.6 | 8.9 | 3.1 |
| **21/04/2020** | 7.6 | 0.1 | 1.2 | 15.3 | 7.3 | 2.6 |
| **23/04/2020** | 2.3 | 0.2 | 1.1 | 12.3 | 11.2 | 3.9 |
| **24/04/2020** | 5.6 | 0.1 | 0.9 | 9.3 | 15.0 | 5.1 |
| **26/04/2020** | 11.2 | 0.2 | 0.8 | 8.5 | 8.6 | 3.0 |
| **29/04/2020** | 10.3 | 0.3 | 1.3 | 15.3 | 9.3 | 3.3 |
| **30/04/2020** | 3.6 | 0.1 | 0.9 | 8.9 | 8.6 | 3.0 |
| **02/05/2020** | 4.5 | 0.2 | 0.9 | 17.3 | 22.1 | 7.6 |
| **03/05/2020** | 6.3 | 0.2 | 1.4 | 15.2 | 8.6 | 3.1 |
| **05/05/2020** | 5.2 | 0.9 | 1.2 | 20.3 | 16.7 | 5.8 |
| **09/05/2020** | 7.1 | 0.5 | 0.3 | 13.2 | 10.5 | 3.6 |
| **11/05/2020** | 7.2 | 0.5 | 0.9 | 11.3 | 6.3 | 2.3 |
| **15/05/2020** | 6.3 | 0.4 | 0.8 | 34.5 | 9.3 | 3.5 |
| **17/05/2020** | 5.2 | 0.1 | 1.0 | 14.3 | 14.4 | 5.0 |
| **20/05/2020** | 9.1 | 0.2 | 0.9 | 13.2 | 10.3 | 3.6 |
| **25/05/2020** | 10.3 | 0.3 | 1.2 | 25.3 | 11.4 | 4.1 |
| **27/05/2020** | 11.2 | 0.1 | 1.1 | 35.2 | 15.3 | 5.5 |
| **02/06/2020** | 9.6 | 0.4 | 1.9 | 50.2 | 11.2 | 4.3 |
| **08/06/2020** | 9.1 | 1.1 | 1.9 | 55.3 | 29.5 | 10.5 |
| **10/06/2020** | 8.6 | 1.3 | 2.1 | 48.3 | 19.8 | 7.2 |
| **12/06/2020** | 5.5 | 1.1 | 2.3 | 47.7 | 12.3 | 4.6 |
| **14/06/2020** | 4.3 | 1.1 | 2.2 | 46.7 | 22.9 | 8.2 |
| **16/06/2020** | 5.6 | 1.2 | 2.1 | 73.4 | 15.8 | 6.0 |
| **18/06/2020** | 8.9 | 1.3 | 2.5 | 67.1 | 24.1 | 8.8 |
| **20/06/2020** | 8.1 | 0.9 | 3.6 | 50.2 | 40.6 | 14.1 |
| **22/06/2020** | 3.5 | 1.6 | 4.5 | 44.3 | 16.3 | 6.0 |
| **24/06/2020** | 7.9 | 1.6 | 4.9 | 45.9 | 24.4 | 8.7 |
| **26/06/2020** | 8.1 | 1.4 | 5.1 | 60.2 | 21.4 | 7.8 |
| **28/06/2020** | 9.1 | 1.0 | 5.2 | 55.3 | 11.2 | 4.4 |
| **30/06/2020** | 6.2 | 0.9 | 9.3 | 51.5 | 16.3 | 6.1 |

Annexure 6. Diurnal variation in $PM_{10}$ and $PM_{2.5}$ concentration

| Sampling Date | 12AM-8AM | 8AM-4PM | 4PM-12AM |
|---|---|---|---|
| **22/4/2020** | 8.2 | 7.6 | 11.3 |
| **25/4/2020** | 9.5 | 8.4 | 12.4 |
| **28/4/2020** | 8.6 | 37.9 | 10.2 |
| **05/04/2020** | 18.3 | 23.7 | 11.3 |
| **05/07/2020** | 15.5 | 8.1 | 23.3 |
| **16/05/2020** | 24.4 | 10.1 | 14.4 |
| **19/05/2020** | 11.3 | 9.9 | 10.6 |
| **Average** | 13.7 | 15.1 | 13.4 |
| **Max** | 24.4 | 37.9 | 23.3 |
| **Min** | 8.2 | 7.6 | 10.2 |
| **Count** | 7 | 7 | 7 |
| **SE** | 2.2 | 4.3 | 1.7 |