Chapter 14
Lessons Learned from the COVID-19 Lockdown for Sustainable Northwestern Himalayan Region

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Abstract This study tried to understand the changes in three air pollution parameters, namely absorbing aerosol index (AAI)—broadly referred to as dust and smoke, nitrogen dioxide (NO_2) and carbon monoxide (CO) column number density in the Western Indian Himalayas during the COVID-19 lockdown. The study used Sentinel 5P data over a 50 km radius of 11 non-attainment cities (NACs) of Northwestern Indian Himalayan states (7 of Himachal Pradesh, 2 of Uttarakhand and 2 of Union Territory of Jammu and Kashmir) during the lockdown phase-1 (March 24–April 14, 2020) with respect to the pre-lockdown period (March 24–April 14, 2019). Ground-measured data on particulate matter (PM_{10}) and nitrogen oxides (NO_x) has also been used for only 7 NACs of Himachal Pradesh for the lockdown phase-1 and pre-lockdown period. The average values of AAI, NO_2 and CO around 11 towns have been reduced by 55%, 19% and 7%, respectively, during lockdown phase-1, compared to the pre-lockdown period. The satellite observation is further complemented through ground-monitored data on air pollution. In the seven NACs of Himachal Pradesh, NO_x and PM_{10} mass concentrations have been substantially reduced during the March and April months of 2020 compared to the same months of 2019. This study would give an idea to environmentalists and policymakers to plan a sustainable emission policy to reduce the adverse impacts of air pollution on the physical aspects (e.g. snow and glaciers) of the Northwestern Himalayan region under the climate change conditions.

Keywords Sentinel 5P · Air quality · COVID-19 · Himalayas · Sustainability

Introduction

Coronavirus disease (COVID-19) caused enormous human death around the world. It is a respiratory disease that transmits from human to human. After analysing a large number of human deaths, an alarming rate of infections and critical illness, the World Health Organisation (WHO) declared COVID-19 as a global pandemic on March 11,

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2020. Many countries including India imposed a lockdown to refrain the transmission rate of new infections by restricting the various types of anthropogenic activities (e.g. factories, non-essential goods market, commercial hubs, transport and personal vehicle movements) at varying scales. Several studies contemplated the effectiveness of COVID-19 lockdown on air pollution across cities around the globe using remote sensing air pollutants data and ground-measured (Kumari and Toshniwal 2020a; Mostafa, Gamal, and Wafiq 2021; Albayati et al 2021). These studies shared findings that reflected the universal decline in most of the air pollutants though the rate of its decline is different at varying spatial scales. Kumari and Toshniwal (2020) quantified air quality data of 162 monitoring stations from 12 cities across the globe and found positive impacts of COVID-19 on the environment. They found a significant reduction in particulate matter ($PM_{2.5}$, PM_{10}) and NO_2 in the lockdown phase as compared to the pre-lockdown phase. Mostafa et al. (2021) shown a reduction in NO_2 (~15–33%), Absorbing Aerosol Index (AAI) (30%), GHG emissions (4%), ozone level (2%) and CO (5%) over Egypt.

Furthermore, *Janta* curfew (people's curfew) was declared on March 22, 2020, by the Government of India. In India, there were 4 phases of lockdown in 2020, i.e. phase-1 (March 25–April 14), phase-2 (April 15–May 03), phase-3 (May 04–17) and finally phase-4 (May 18–31) (Pathakoti et al. 2020). During the lockdown phase-1 period, public transport came to a complete halt, which is considered to be the main source of air pollution in most of the Indian cities. All factories, markets, shops and construction works remained suspended across the world and Indian sub-continent. Yadav et al. (2020) assessed the major pollutants in 4 Megacities of India during the COVID-19 lockdown with the past several years (2013–2019). They reported a sharp decline in NO_2 levels (60–65%) and $PM_{2.5}$ and PM_{10} levels (30–50%). Similar results have also been shown by other studies over the different parts of India (Mahato et al. 2020; Sharma et al. 2020; Kumari and Toshniwal 2020b; Thomas et al. 2020; Nigam et al. 2021; Rani et al. 2021). Such findings are likely to have serious implications for policy makers in making strategies.

Pre-COVID studies in the Hindu Kush-Himalayan region have advocated the presence of anthropogenic black carbon (BC), fly ash, dust particles, nitrogen dioxide (NO_2 and surface ozone (O_3) (Ramanatham and Carmichael 2008; Bonasoni et al. 2021). The small amount of BC along with other air pollutants can modify the reflectance from the snow that can further enhance the rate of snowmelt and areal coverage of snow (Bonasoni et al. 2021). Against the backdrop of mentioned studies, the present study eventually establishes this direction to look upon the air quality scenario during the lockdown phase-1 (March 24–April 14, 2020) and pre-lockdown period (March 24–April 14, 2019) for 11 hill towns of the Northwestern Himalayas (NWH) (Himachal Pradesh, Uttarakhand and Jammu and Kashmir) falling under the non-attainment category of cities/towns of India. The ground-measured data on PM_{10}, NO_2 and Sentinel 5p measured data on AAI, NO_2 and carbon monoxide (CO) have been used to quantify the magnitude of change in these parameters of air quality during lockdown phase-1 compared to the pre-lockdown period.

Study Area

The Central Pollution Control Board of India had, in the first instance, identified 102 NACs across 23 Indian states and Union Territories based on their ground monitored ambient air quality data between 2011 and 2015. In India, cities were considered as NAC if they were consistently showing poorer air quality than the Indian National Ambient Air Quality Standards (NAAQS). NAC falling in the NWH comprise of seven towns of Himachal Pradesh (Baddi, Nalagarh, Parwanoo, Paonta Sahib, Kala Amb, Sundernagar and Damtal), two towns of Uttarakhand (Kashipur and Rishikesh) and two towns of Jammu and Kashmir UT (Jammu and Srinagar). The study area comprises geographical areas falling under a 50 km radius of 11 NACs falling in western Himalayan states of Himachal Pradesh, Uttarakhand and Jammu and Kashmir UT (Table 14.1 and Fig. 14.1).

Table 14.1 Geographical locations and elevation in above mean sea level (AMSL)

S. No	Name of the NAC	Latitude and longitude	Elevation (AMSL)
1	Baddi	30°56′30.89"N, 76°48′12.02"E	445
2	Nalagarh	31° 2′45.39"N, 76°42′9.72"E	346
3	Parwanoo	30°50′26.11"N, 76°57′30.15"E	779
4	Paonta Sahib	30°26′44.03"N, 77°36′15.47"E	397
5	Kala Amb	30°29′57.19"N, 77°12′25.59"E	337
6	Sundernagar	31°31′47.61"N, 76°53′20.20"E	878
7	Damtal	32°13′32.71"N, 75°39′36.30"E	313
8	Kashipur	29°12′37.56"N, 78°57′42.75"E	236
9	Rishikesh	30° 5′12.64"N, 78°16′3.64"E	371
10	Jammu	32°43′35.40"N, 74°51′25.77"E	310
11	Srinagar	34° 5′1.01"N, 74°47′50.23"E	1588

Fig. 14.1 Location map of 11 non-attainment towns/cities (NACs) of Northwestern India Himalaya considered in the present study

Materials and Methods

Multi-time-series Sentinel 5P Satellite data (March, 24 to April 14, 2020 and 2019) were retrieved from https://s5phub.copernicus.eu (via the Copernicus Data and Information Access). Further, these data were pre-processed and analysed/visualised in PanoplyWin-4.10.8 and Sentinel Application Platform (SNAP) 7.0 desktop applications. The spatial resolution of satellite data is 3.5 km × 7.5 km. The mean value of the aerosol index, NO_2 and CO of all sentinel 5p imageries for the period March 24 to April 14, 2019, was calculated for the pre-lockdown period and compared with same the period from March 24 to April 14, 2020, for the lockdown phase-1 period. Further, these mean images were clipped with the region of interest, i.e. around 50 km of point features of 11 towns for the bands of AAI, NO_2 column number density and CO column number density for the pre-lockdown period and post lockdown period. The list of Google Earth engine datasets and bands are as below:

- COPERNICUS/S5P/OFFL/L3 AER AI (absorbing aerosol index),
- COPERNICUS/S5P/OFFL/L3 NO_2 (NO_2 column number density),
- COPERNICUS/S5P/OFFL/L3 CO (CO column number density).

Subsequently, zonal statistics for mean value was derived for each region of NAC using GIS software. PM_{10} and NOx data were obtained from the Himachal Pradesh State Pollution Control Board for the lockdown phase-1 and pre-lockdown period. Changes in AAI, NO_2 and CO have been computed as follows:

$$\text{Absolute changes in air pollutants} = P_2 - P_1 \tag{14.1}$$

$$\%\ \text{change in air pollutants} = \frac{P_2 - P_1}{P_1} \times 100 \tag{14.2}$$

where P_1 is representing air pollutant concentrations during the reference and pre-lockdown period while P_2 is denoting the lockdown phase-1.

Results and Discussion

Reduction in AAI, NO_2 and CO

The main sources of NO_2 emissions are fertilisers and the combustion of fossils fuels. Besides this, CO is a good indicator of air pollution. The main sources of CO emissions are vehicles, industries and burning of forests and grasses. The average values of AAI, NO_2 and CO around 11 towns have been reduced by 55%, 19% and 7%, respectively, during lockdown phase-1 concerning the pre-lockdown period (2019) (Table 14.2). The range of reduction in AAI values varies from 32% (Sundernagar) to 92% (Kashipur). Substantial reduction in AAI values has been observed around all 11 cities. It is pertinent to note that positive values of the aerosol index generally represent absorbing aerosols (dust and smoke) while small or negative values represent non-absorbing aerosols. The range of reduction in tropospheric NO_2 density varies from 14% (Jammu) to 25% (Baddi). A substantial reduction in NO_2 has also been observed around all 11 towns. The range of reduction in CO density varies from 0 (Srinagar) to 10% (Kashipur) (Table 14.2). Similar findings of improvement in air quality have also been reported by other studies over the Himalayan region (Biswal et al 2020; Bahukhandi, Agarwal, and Singhal 2020; Moore and Semple 2021).

Table 14.2 Changes in AAI, NO_2 and CO in cities of NW Himalayas during the lockdown period phase-1

Town/city	Pre-lockdown (2019)	During lockdown (2020)	% change	Pre-lockdown (2019)	During lockdown (2020)	% change	Pre-lockdown (2019)	During lockdown (2020)	% change
		AAI			NO_2			CO	
Damtal	−0.98	−1.43	−46	0.00008	0.00006	−17	0.036	0.033	−8
Nalagarh	−0.86	−1.3	−51	0.00008	0.00006	−23	0.0356	0.033	−7
Baddi	−0.8	−1.25	−56	0.00009	0.00007	−25	0.0356	0.033	−7
Sundernagar	−1.17	−1.55	−32	0.00007	0.00006	−16	0.031	0.03	−3
Parwanoo	−0.84	−1.32	−57	0.00008	0.00007	-22	0.034	0.032	-6
Kala Amb	−0.72	−1.3	−81	0.00009	0.00007	−22	0.037	0.034	−8
Paonta Sahib	−0.77	−1.31	−70	0.00008	0.00006	−19	0.034	0.032	−6
Kashipur	−0.6	−1.15	−92	0.00008	0.00007	−16	0.04	0.036	−10
Rishikesh	−0.77	−1.36	−77	0.00008	0.00007	−17	0.036	0.033	−8
Srinagar	−1.05	−1.46	−39	0.00007	0.00006	−14	0.028	0.028	0
Jammu	−0.93	−1.3	−40	0.00008	0.00007	−14	0.035	0.033	−6
Average	−0.9	−1.3	−55.2	0.00008	0.00006	−19	0.035	0.032	−7

Reduction in Ground-Measured PM_{10} and NO_x

In the seven towns/cities of Himachal Pradesh, PM_{10} mass concentration has been substantially reduced during the March and April months of 2020 compared to the same months of 2019 (Fig. 14.2). PM_{10} concentration is almost nil in Kala Amb and Nalagarh towns during the March and April months of 2020 (Fig. 14.2). Reduction in nitrogen oxides (NO_x) is also showing a similar trend as PM_{10} during the March and April months of 2020 compared to the same months of 2019 (Fig. 14.3).

The study area receives a part of its air pollution from outside including the Indo-Gangetic Plain (IGP) due to trans-boundary air pollution movement. Further, high concentrations of pollutants in the IGP seem to have partial trans-boundary natural movement over the lower mountains of the Himalayas. These NACs are located along the transitional zone from mountain to plains, hence witness partial concentrations of air pollutants. Sentinel 5P data comprehensively establish that there has been a decline in air pollution concentration over the NACs of Northwestern Indian Himalaya (NWIH) coinciding with nationwide lockdown to stop the spread of the coronavirus (COVID-19) started during the last week of March 2020.

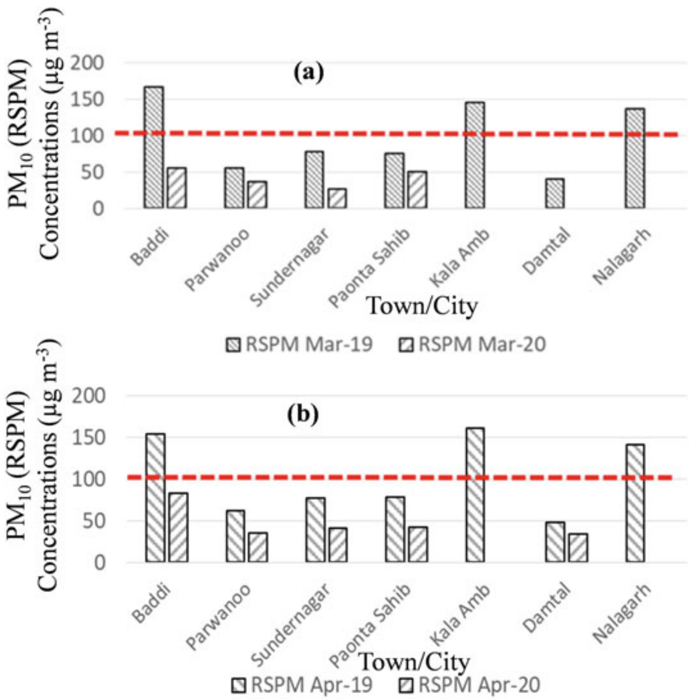

Fig. 14.2 PM_{10} (RSPM) concentrations ($\mu g\ m^{-3}$) in 7 NACs of Himachal Pradesh during **a** March 2019–2020 and **b** April 2019–2020 (24 h average standard = 100 $\mu g\ m^{-3}$)

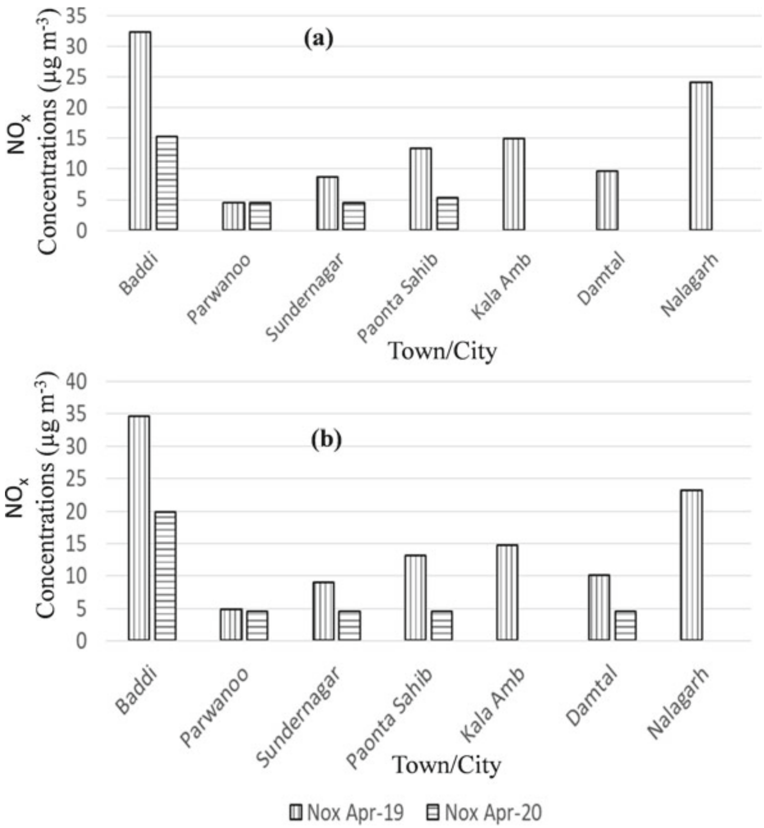

Fig. 14.3 NO_x concentrations ($\mu g\ m^{-3}$) in 7 NACs of Himachal Pradesh during **a** March 2019–2020 and **b** April 2019–2020 (24 h average standard = 80 $\mu g\ m^{-3}$)

This led to the dramatic reduction in the concentration of particulate matter and other trace gases such as NO_2 and CO over the study area. The NWIH has traditionally been recording low concentrations of PM, smoke and other pollutants owing to its mountainous location. Over one-fourth of the total geographical area of the NWIH states seems to fall under forest cover, which contributes to absorbing localised air pollutants. However, the relatively low concentration of air pollution seems to originate mainly due to emissions from the transport sector, stubble burning and forest fire from surrounding areas. The present study is important for environmentalists and policy makers because some previous studies have reported the negative impact of air pollution on snow and glacier (Kang et al. 2019, 2020). In this context, such reduction in air pollution would improve the physical aspects of the Himalayan region and can be adopted as a strategy to minimise the impact of climate change as well. Guttikunda and Nishadh (2020) while reporting the positive influence of COVID-19 lockdown on air quality stated to achieve and maintain national ambient norms, we must employ an air shed strategy in which reductions in the city are supplemented by equal reductions throughout the area.

Such findings are likely to have many implications for policy makers in making strategies under the increasing climate change impacts. It would be useful to improve the sustainability of the fragile Himalayan ecosystem.

Conclusions

The air quality concerning aerosol, tropospheric NO_2, CO, PM_{10} and NO_x of the NACs of NWIH is observed to be low before and during lockdown phase-1 though with a declining trend during the lockdown. The anthropogenic activities and natural trans-boundary movement of pollutants both seem to contribute to whatever pollution level prevails in these towns. However, closure of all factories, markets, shops and construction works and suspension of vehicular movement seem to contribute towards further declining concentration of aerosol, tropospheric NO_2 and CO during lockdown phase-1. The improvement in the air quality of the study area has been established across all NACs in terms of AAI, NO_2 and CO parameters, which is well supplemented by ground-monitored values of the Pollution Control Board. Though, the size of cities and their geographical settings and other economic activities such as industrial activities and vehicular movement were strongly correlated with pollution concentrations. A substantial share of reduction of emissions seemed to come from the transport sector. But further research is needed in this respect and also on positive/negative feedbacks of air pollution reduction on snowmelt during the lockdown phase-1. This study would be beneficial for environmentalists and policymakers to plan a sustainable emission policy to reduce the adverse impacts of air pollution on the physical aspects (such as snow/glaciers) of the Western Himalayan region.

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