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## Seasonal variation assessment of ambient air quality during COVID-19 lockdown in Uttarakhand state, India

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**सार** – वर्तमान में, वायु प्रदूषण दुनिया भर में एक महत्वपूर्ण पर्यावरणीय खतरा बना हुआ है। हालाँकि, वायु प्रदूषकों की भिन्नता काफी हद तक मौसम में बदलाव (मॉनसून पूर्व, मॉनसून, मॉनसून उपरांत और शीत ऋतु), जलवायु परिस्थितियों और कुछ मानवजनित गतिविधियों से जुड़ी होती है। हाल ही में, दुनिया के विभिन्न हिस्सों में COVID-19 लॉकडाउन के कारण वायु प्रदूषकों के स्तर में उल्लेखनीय गिरावट देखी गई है। इसलिए, यह अध्ययन भारत के उत्तराखंड राज्य की वायु गुणवत्ता पर COVID-19 प्रतिबंधों (लॉकडाउन से पहले और लॉकडाउन के बाद) के प्रभाव का आकलन करने के लिए किया गया। प्रयोजनात्मक रूप से, उत्तराखंड प्रदूषण नियंत्रण बोर्ड द्वारा एकत्र किए गए 8 स्टेशनों से वायु गुणवत्ता डेटा का विश्लेषण किया गया। निष्कर्षों से पता चला कि PM<sub>10</sub>, PM<sub>2.5</sub>, SO<sub>2</sub>, and NO<sub>2</sub> सहित वायु प्रदूषकों की औसत सांद्रता में सार्थक भिन्नता थी। हालाँकि, परिवेशी वायु प्रदूषण में कणिकापदार्थ शीर्ष योगदानकर्ताओं में से एक है, जबकि SO<sub>2</sub> और NO<sub>2</sub> जैसे गैसीय प्रदूषक केंद्रीय प्रदूषण नियंत्रण बोर्ड (CPCB) द्वारा दिए गए मानकों से नीचे हैं। वर्तमान अध्ययन ने पुष्टि की है कि पिछले वर्ष (2019) की तुलना में, 2020 में प्रारंभिक लॉकडाउन के दौरान, SO<sub>2</sub>, NO<sub>2</sub>, PM<sub>2.5</sub> और PM<sub>10</sub> की सांद्रता में क्रमशः 9.46-86.4%, 20-74.6%, 35.6-62.6% और 14.7-65% की उल्लेखनीय कमी आई। जबकि अगले वर्ष (2021) की तुलना में क्रमशः -11.6 -96.5%, -9.5 -70.6%, 5.1-57.6% और -17.06-71.7% की उल्लेखनीय वृद्धि देखी गई। इसके अलावा, विभिन्न ऋतुओं में वायु प्रदूषकों में काफी भिन्नता और लॉकडाउन अवधि के दौरान वायु गुणवत्ता सूचकांक (एक्यूआई) में आश्चर्यजनक सुधार देखा गया। इस कार्य के निष्कर्षों से पता चलता है कि बाहरी मानवीय गतिविधियों में कमी से भारत के उत्तराखंड राज्य की परिवेशी वायु गुणवत्ता में महत्वपूर्ण सुधार हो सकता है।

**ABSTRACT.** Presently, air pollution remains a significant environmental threat across the world. However, variation of air pollutants is largely associated with changes in season (pre-monsoon, monsoon, post-monsoon, and winter), climatic conditions, and certain anthropogenic activities. Recently, a significant drop in the levels of air pollutants has been observed due to the COVID-19 lockdown in various parts of the world. Therefore, this study was performed to assess the impact of COVID-19 restrictions (pre-lockdown and post-lockdown) on the air quality of Uttarakhand state, India. Purposively, the air quality data from 8 stations collected by the Uttarakhand pollution control board was analyzed. The findings showed that there was a significant variation in the average concentration of air pollutants including, PM<sub>10</sub>, PM<sub>2.5</sub>, SO<sub>2</sub> and NO<sub>2</sub>. However, particulate matter is amongst the top contributors to ambient air pollution while gaseous pollutants such as SO<sub>2</sub> and NO<sub>2</sub> are below the standards given by the Central Pollution

Control Board (CPCB). The present study confirmed that during the initial lockdown in 2020, the concentration of SO<sub>2</sub>, NO<sub>2</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> decreased significantly by 9.46-86.4%, 20-74.6%, 35.6-62.6%, and 14.7-65% respectively as compared to the previous year (2019) while a significant corresponding increase by -11.6-96.5%, -9.5-70.6%, 5.1-57.6% and -17.06-71.7% was observed, respectively in comparison to the succeeding year (2021). Moreover, a considerable variation of air pollutants in different seasons and a dramatic improvement in the air quality index (AQI) were observed during the lockdown period. The findings of this work suggest that the decrease in outdoor human activities could contribute a significant improvement in the ambient air quality of the state of Uttarakhand, India.

**Key words**– Air pollution, Anthropogenic activities, AQI, CPCB standards, PM<sub>2.5</sub>.

## 1. Introduction

The development of technologies, expansion in urbanization, industrialization, and transportation have contributed to the rapid growth of human civilization (Giri and Pant 2018a). However, the drastically increased human population has been continuously creating a burden on all spheres of the earth (Goswami *et al.*, 2021; Pant *et al.*, 2017). This leads to poor management of natural resources and thus, progression towards a global threat as environmental pollution (Dandotiya 2020; Goswami *et al.* 2022; Singh *et al.* 2020), which ultimately leads to declination in life expectancy, disturbing ecosystem health, and economies (Giri and Pant 2018b; Liang and Gong 2020). Air pollution results when excess amounts of gases, particles, and aerosols are released due to anthropogenic activities and natural phenomena such as forest fires, earthquakes, tsunami, volcanic events, *etc.* which later alters the natural composition of the atmosphere (Kumar and Dash 2018; Giri and Pant 2018b). However, the atmosphere recovers its original composition slowly through several parameters like meteorological conditions, pollutant emission, dispersion, and physicochemical transformation, which influence the ambient air quality of a specific area (Liang and Gong 2020). Sources of NO<sub>2</sub> emission include vehicular emissions, industries, coal-fired power plants (Sulaymon *et al.* 2021), which lead to alveoli irritation and hindrance in pulmonary functions (Dandotiya 2020). Sulphur-containing fuels and coal-based thermal power plants are associated with SO<sub>2</sub> emissions (Singh *et al.*, 2020), which lead to respiratory disorders, bronchitis, and lower birth rate (Dandotiya 2020). Globally, particulate matter (PM) has been known as one of the most critical environmental threats and is associated with morbidity and mortality due to respiratory and cardiovascular diseases (Pant *et al.* 2019; Sharma and Mandal 2017; Sulaymon *et al.* 2021). Globally, air pollution was recorded as the fifth-highest mortality risk factor with 147 million healthy lives lost in 2017 (Health Effects Institute 2019). In today's world, more than 90% of the population is living in an area where air quality exceeds the limits given by WHO (WHO, World Health Organization 2020). Continuous exposure to air pollution will be the cause of a rise in annual premature mortality rate by 0.2 million to 1.4 million in 2040, from which 60% of deaths are estimated to be caused by ambient air pollution (IEA 2021).

Recently, the unexpected outbreak of the coronavirus pandemic (SARC-CoV-2) has resulted in significant positive changes in the environment with the improvement in air quality across the globe (Adelodun *et al.* 2021a; Gope *et al.* 2021). COVID-19 was first identified in Wuhan, Central China in December 2019, affecting many countries by an infection that spreads mainly from humans to humans (Sulaymon *et al.* 2021; WHO 2020). In order to prevent the spread of COVID-19, a nationwide lockdown in India, restricting anthropogenic activities like transportation, construction, industries, schools, colleges, malls, flights, restaurants, and other non-essential activities, was initiated in various phases (Adelodun *et al.* 2021b; Mahato *et al.* 2020; MHA 2020; Roy *et al.* 2021). The first phase was implemented for 21 days (25<sup>th</sup> March - 14<sup>th</sup> April), then extended from 15<sup>th</sup> April to 3<sup>rd</sup> May, then 4<sup>th</sup> May to 17 May, and a further 18 May to 31 May. All the lockdown processes lead to modifying overall air quality (Chakraborty *et al.* 2021; Dhaka *et al.* 2020; Mahato *et al.* 2020; Roy *et al.* 2021; Sarkar *et al.* 2020). The fuel consumption rate during the lockdown period was reduced by 40%, 50-60%, 70% and 90% due to shut down in activities like industries, transportation, construction, and aviation, while household fuel consumption rate was increased by 12% (Singh *et al.* 2020). Overall, processes eventually lead to a decline in PM<sub>2.5</sub> level by 25-60% (Gope *et al.* 2021). This evidence has inspired researchers and policymakers to study the impression of reduced emissions on air quality across India. Tremendous declination in air pollution based on satellite data of the lockdown period due to the COVID-19 pandemic has also been observed in various studies (Liu *et al.* 2021; Singh and Chauhan, 2020; Adelodun *et al.* 2021c). In Wuhan city, an immediate increase in the concentration of NO<sub>2</sub>, O<sub>3</sub> and PM<sub>10</sub> was observed after the lockdown was over. It is an alarm that further control approaches must be implemented for constant improvement in air quality. Otherwise, we will return to a similar polluted world again (Sulaymon *et al.* 2021). Many studies from the megacities across the globe are available on the lockdown impacts and variability in the pollution parameters (Gao *et al.*, 2020; Liu *et al.* 2021; Morales-Solís *et al.*, 2021; Singh and Chauhan, 2020; Sulaymon *et al.*, 2021; Vadrevu *et al.*, 2020) including India. However, no such study has been done till date emphasizing air pollutants and lockdown due to COVID-19 in Uttarakhand state. Therefore, this study assessed the

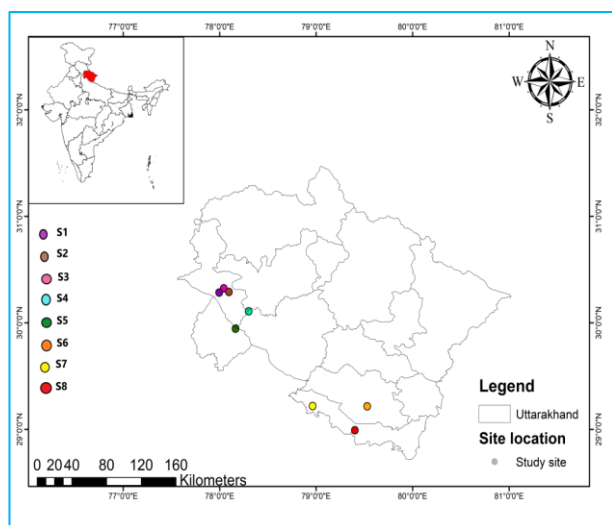


Fig. 1. Location map of air quality monitoring stations in Uttarakhand

air quality changes at eight ground monitoring stations across Uttarakhand during the COVID-19 lockdown and trends in seasonal and monthly variation of ambient air pollutants along with air quality index (AQI).

## 2. Data and methodology

### 2.1. Study area

Uttarakhand lies between 28° 44' to 31° 28' N latitude and 77° 35' to 81° 01' E longitude and occupies an area of 53,483 km<sup>2</sup> and has a population of nearly 1.01 crores and is referred to as “Devbhoomi (Land of Gods)”. The Himalayan state of Uttarakhand has high altitude mountains as well as foothill plain landscapes and densely populated districts. The measurements of particulate (PM<sub>2.5</sub> and PM<sub>10</sub>) and gaseous (SO<sub>2</sub> and NO<sub>2</sub>) air pollutants for all the eight air quality monitoring stations were made by the Uttarakhand Pollution Control Board ([ueppcb.uk.gov.in](http://ueppcb.uk.gov.in)) and utilized for this study. The National Air Monitoring Programme (NAMP) by the Central Pollution Control Board (CPCB) has been monitoring ambient air quality at eight monitoring stations in Uttarakhand state, *viz.*, Clock Tower (S1), Raipur Road (S2) and Himalayan Drug, Inter State Bus Terminal (ISBT), Dehradun (S3), Nagar Palika Parishad, Rishikesh (S4), State Industrial Development Corporation of Uttarakhand Limited (SIDCUL), Haridwar (S5), Government Hospital, Haldwani (S6), Government Hospital, Kashipur (S7) and Government Hospital, Rudrapur (S8) (Fig. 1). The locations have been categorized on a land-use basis, *i.e.*, residential, industrial, or ecologically sensitive. The monitoring locations of Kashipur and Rudrapur are sensitive ones, while others

TABLE 1

Air quality index (AQI) categories, ranges and their health impacts

AQI	Air Pollution Level	Levels of health concern
0-50	Good	Good
51-100	Satisfactory	Moderate
101-200	Moderately	Unhealthy for sensitive groups
201-300	Poor	Unhealthy
301-400	Very Poor	Very unhealthy
401-500	Severe	Hazardous

come in the residential or industrial zone. The location of all these eight air quality monitoring stations is marked in Fig. 1.

### 2.2. Data sources

The monthly average measurements on the concentration of air pollutants were obtained from the online data source of Uttarakhand Pollution Control Board, India (<http://ueppcb.uk.gov.in>). The method used for measurement of SO<sub>2</sub> is the Improved West & Gaeke method, Jacob & Hochheiser modified method for NO<sub>2</sub> monitoring and the Gravimetric method for PM's monitoring (NAAQS 2011). The database of meteorological parameters such as rainfall (R), temperature (T), relative humidity (RH), wind speed (WS) and wind direction (WD) was collected from IMD (India Meteorological Department), Dehradun on a daily basis.

### 2.3. Data analysis

The analysis is divided into four sections, the trend in monthly variation and seasonal variation of annual data (March, 2019-Feb, 2020) for SO<sub>2</sub>, NO<sub>2</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> concentration with air quality index (AQI). Assessment of pollutants during lockdown (March, April and May, 2020), pre-lockdown (March, April and May, 2019) and post-lockdown (March, April and May, 2021) periods was carried out to compare the percentage changes or variations during this period. Correlation analysis is performed among the mean concentration of pollutants, among the concentration of pollutants from pre-lockdown, lockdown, and post-lockdown period, and mean concentration of pollutants with the available meteorological parameters of highly polluted study sites S1, S2, and S3. Air mass backward trajectories using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPPLIT, PC-version) model (Draxler and Rolph, 2011) were also used to delineate the possible source region of pollutants.

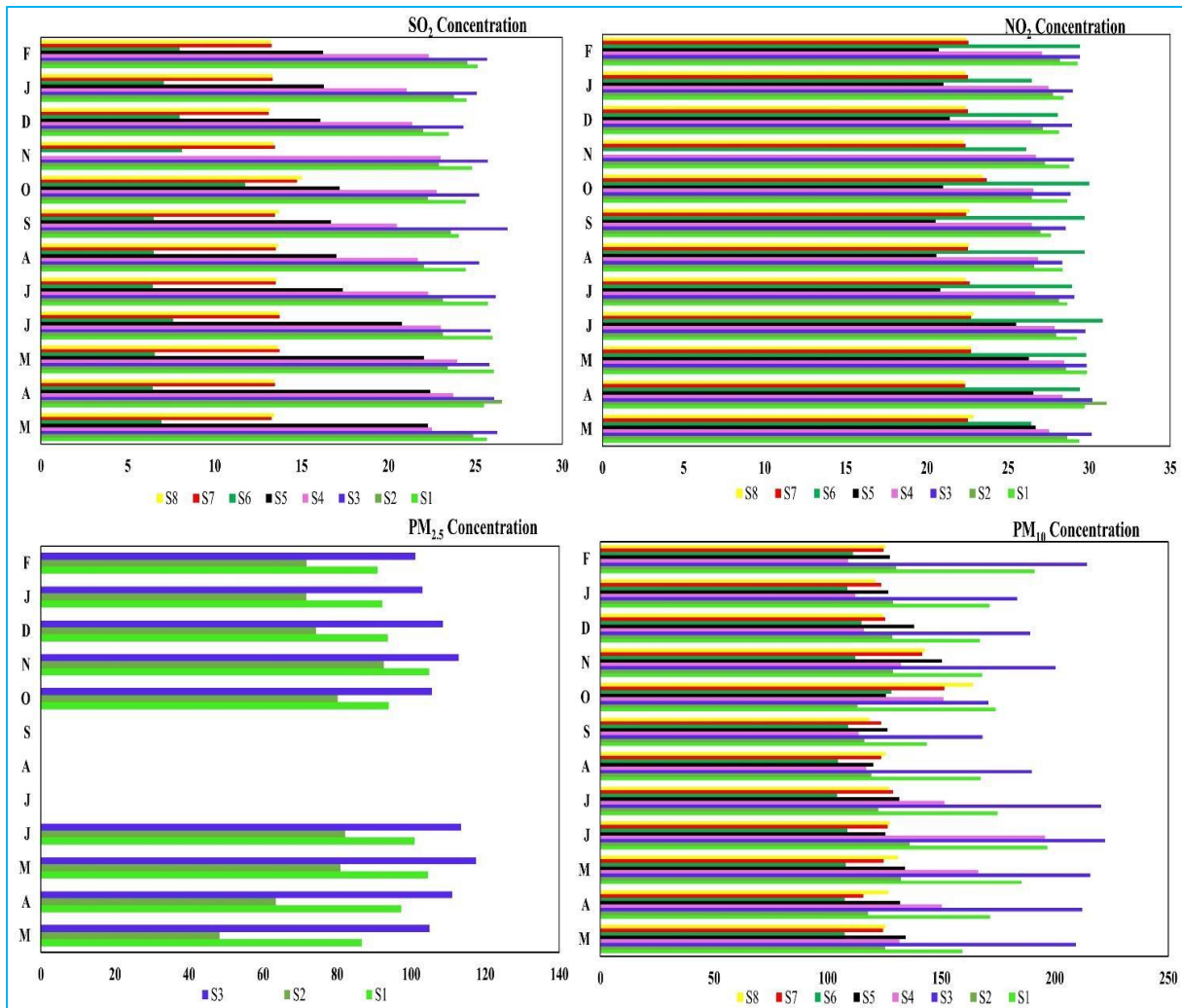


Fig. 2. Monthly average variation in concentration of pollutants during 2019-2020 (J to D: January to December)

### 2.3.1. Air Quality Index (AQI)

The index for reporting daily air quality is AQI. It states how clean or polluted the air is with its associated impacts on health. In this study, an attempt has been made to evaluate the AQI of the study sites and to categorize them based on their pollution potential as per the standards of the Government of India. The AQI ranges from 0 to 500. A higher AQI value shows a greater level of air pollution and health concerns (Table 1). AQI for the study sites is calculated by using the equation (1) (Rao and Rao 1998; Dadhich *et al.* 2018):

$$AQI = \frac{1}{4} \times \frac{SO_2 \text{ Actual}}{SO_2 \text{ Standard}} + \frac{NO_2 \text{ Actual}}{NO_2 \text{ Standard}} + \frac{PM \text{ Actual}}{PM \text{ Standard}} \times 100 \quad (1)$$

## 3. Results and discussion

### 3.1. Monthly variation of pollutants

The key sources of PM<sub>2.5</sub> and PM<sub>10</sub> are emissions from industrial processes, construction works, road traffic, biomass burning, and dust re-suspension (Sharma and Mandal 2017). In the previous studies, Chauhan *et al.* (2010) and Joshi and Semwal (2011) observed that the PM's was the dominant air pollutants, which were above the permissible limit in the Haridwar region of Uttarakhand. Awasthi *et al.* (2016) observed that the industrial establishment has increased the concentration of different pollutants in the ambient air over six years of monitoring. However, it was observed that the concentration of SO<sub>2</sub> and NO<sub>x</sub> have increased by 2-2.5 times, and RSPM and SPM have increased by 1.5-1.7 times during the study period. The monthly mean

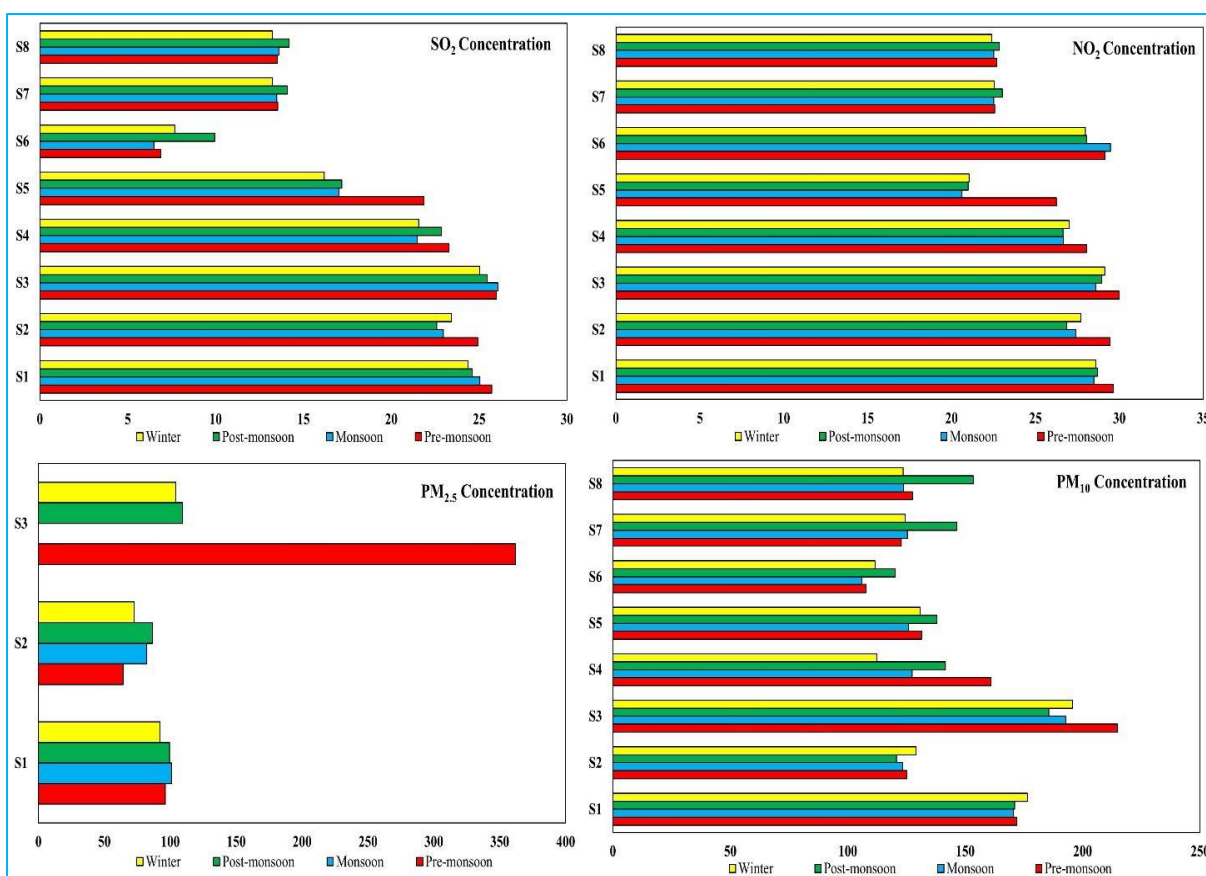


Fig. 3. Seasonal variation in concentration of pollutants during 2019-2020

concentration of air pollutants of eight monitoring sites is depicted in Fig. 2. The monthly mean concentration of SO<sub>2</sub> varies from 23.47-26.06  $\mu\text{g m}^{-3}$ , 21.99-26.51  $\mu\text{g m}^{-3}$ , 24.32-26.84  $\mu\text{g m}^{-3}$ , 20.48-23.95  $\mu\text{g m}^{-3}$ , 16.08-22.40  $\mu\text{g m}^{-3}$ , 6.44-11.77  $\mu\text{g m}^{-3}$ , 13.10-14.72  $\mu\text{g m}^{-3}$ , 13.17-15.02  $\mu\text{g m}^{-3}$  at monitoring sites S1 to S8, respectively. Similarly, the monthly average concentration of NO<sub>2</sub> was reported in the range of 27.66-29.87  $\mu\text{g m}^{-3}$ , 26.48-31.1  $\mu\text{g m}^{-3}$ , 28.35-30.19  $\mu\text{g m}^{-3}$ , 26.44-28.46  $\mu\text{g m}^{-3}$ , 20.60-26.69  $\mu\text{g m}^{-3}$ , 26.12-30.82  $\mu\text{g m}^{-3}$ , 22.35-22.72  $\mu\text{g m}^{-3}$ , 22.26-23.43  $\mu\text{g m}^{-3}$  at monitoring sites S1 to S8, respectively.

The average concentration of SO<sub>2</sub> and NO<sub>2</sub> was maximum during the April-May month while the minimum was during the December and October-November months of the year, respectively. The monthly mean concentration of PM<sub>10</sub> was in the range of 143.58-196.74  $\mu\text{g m}^{-3}$ , 113-136.15  $\mu\text{g m}^{-3}$ , 168.16-222.01  $\mu\text{g m}^{-3}$ , 109.02-195.71  $\mu\text{g m}^{-3}$ , 120.17-150.3  $\mu\text{g m}^{-3}$ , 104.27-128.07  $\mu\text{g m}^{-3}$ , 115.78-151.47  $\mu\text{g m}^{-3}$ , 118.46-164.08  $\mu\text{g m}^{-3}$  at monitoring sites S1 to S8, respectively. The dataset of PM<sub>2.5</sub> is available only for 3 sites and the average concentration of PM<sub>2.5</sub> was maximum in November while minimum in the February-March month. Similarly, the

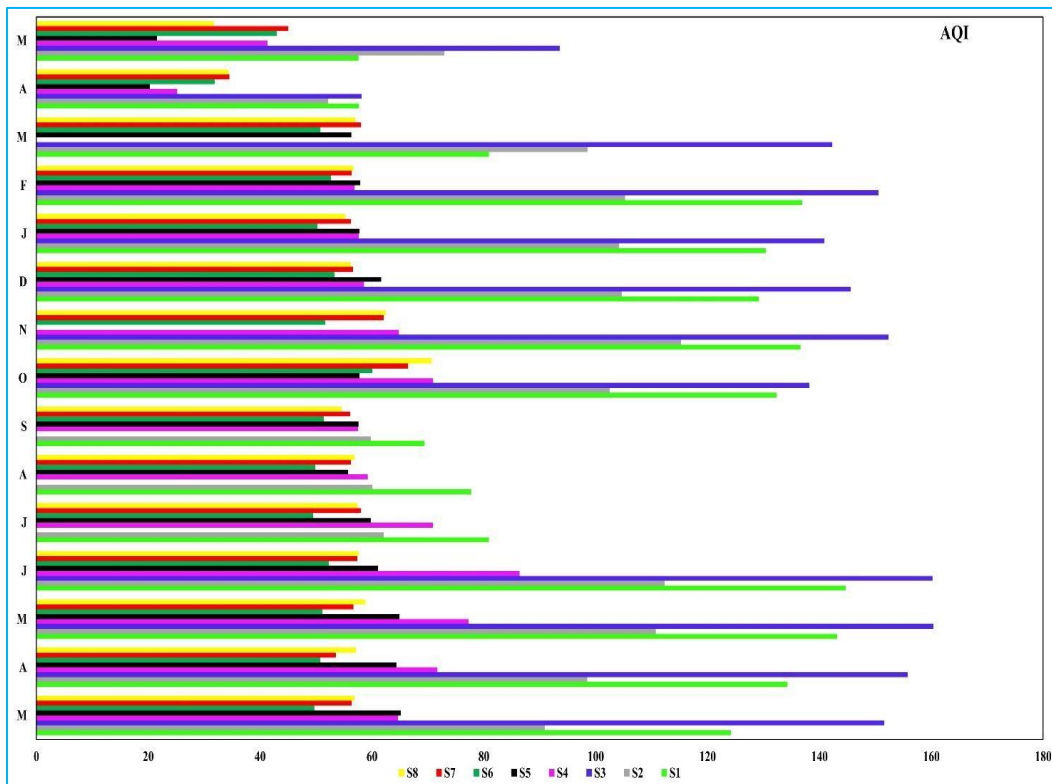
average concentration of PM<sub>10</sub> was maximum in January and minimum in the September month of the year. Stable weather conditions, lowering of the boundary layer and the formation of an inversion layer confines the pollutants by lowering the mixing heights which cause high pollution levels during winters (Dhaka *et al.*, 2020). A strong rainfall pattern may be the reason for scavenging of pollutants from the atmosphere, which causes relatively less concentrations of SO<sub>2</sub>, NO<sub>2</sub> and PM's during October- November.

### 3.2. Seasonal variation of pollutants

The Indian meteorological department (IMD) classifies the seasons as pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November), and winter (December-February), which is referred to here. The seasonal variation of air pollutants (SO<sub>2</sub>, NO<sub>2</sub>, PM<sub>2.5</sub> and PM<sub>10</sub>) for monitoring sites is shown in Fig. 3. Strong monsoon patterns assist in scavenging pollutants during the monsoon season, as shown in industrial sites S3 and S5 where the concentration of pollutants was highest during the pre-monsoon or post-monsoon season and minimum during monsoon season.

**TABLE 2**  
**National Ambient Air Quality Standards (NAAQS)**

Pollutant	Time-weighted average	Concentration in ambient air	
		Industrial areas, Residential, Rural & other areas	Ecological sensitive area
Sulphur dioxide (SO <sub>2</sub> ) (µgm <sup>-3</sup> )	Annual	50	20
	24 hours	80	80
Nitrogen dioxide (NO <sub>2</sub> ) (µgm <sup>-3</sup> )	Annual	40	30
	24 hours	80	80
PM <sub>10</sub> (µgm <sup>-3</sup> )	Annual	60	60
	24 hours	100	100
PM <sub>2.5</sub> (µgm <sup>-3</sup> )	Annual	40	40
	24 hours	60	60
Ozone (O <sub>3</sub> ) (µgm <sup>-3</sup> )	8 hours	100	100
	1 hour	180	180
Lead (Pb) (µgm <sup>-3</sup> )	Annual	0.50	0.50
	24 hours	1.0	1.0
Carbon monoxide (CO) (mgm <sup>-3</sup> )	8 hours	02	02
	1 hour	04	04
Ammonia (NH <sub>3</sub> ) (µgm <sup>-3</sup> )	Annual	100	100
	24 hours	400	400
Benzene (C <sub>6</sub> H <sub>6</sub> ) (µgm <sup>-3</sup> )	Annual	5	5
Benzo (a) Pyrene (BaP) (ngm <sup>-3</sup> )	Annual	1	1
Arsenic (As), ngm <sup>-3</sup>	Annual	6	6
Nickel (Ni), ngm <sup>-3</sup>	Annual	20	20



**Fig. 4.** Air Quality Index (AQI) during the year 2019-2020

TABLE 3

## Percentage reduction in the concentration of pollutants

Site	SO <sub>2</sub>		NO <sub>2</sub>		PM <sub>2.5</sub>		PM <sub>10</sub>	
	April	May	April	May	April	May	April	May
S1	70.8	32	69.9	27.8	51	-	57	33
S2	74.6	40	74.6	35	41.5	42.7	35	24
S3	64.9	40.3	61.4	33.3	62.6	35.6	62.6	48.7
S4	74.8	52.2	73	48.8	-	-	61	45
S5	86.4	83.9	66.8	70	-	-	65	63
S6	21.5	9.4	43.5	20	-	-	36	14.7
S7	35.3	24.7	41	35.6	-	-	34	16.5
S8	35.7	62.8	40	27	-	-	35.4	20.5

Deep *et al.* (2018) also observed that the concentration of pollutants is higher during the pre-monsoon season as compared to the winter and the monsoon seasons. The mean concentration of SO<sub>2</sub>, NO<sub>2</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> was highest during the pre-monsoon season or winter season while the reduction in the concentration of pollutants during monsoon season was due to the scavenging of pollutants by rainfall. During winters, the air quality level was more polluted than other seasons (Chen *et al.* 2015; Kumar and Dash 2018). In another study, Deep *et al.* (2019) also analyzed the variability of SO<sub>2</sub>, NO<sub>2</sub>, SPM, and PM<sub>10</sub> concentration in Dehradun city, from 2011 to 2014. The PM<sub>10</sub> and SPM were found to vary above the permissible limits by CPCB (between 150-195 µgm<sup>-3</sup> and 350-470 µgm<sup>-3</sup> during winter and summer respectively).

From the above results, we found that the concentration of SO<sub>2</sub> and NO<sub>2</sub> were in the range of the prescribed limit by CPCB (Table 2) while the concentration of PM<sub>2.5</sub> and PM<sub>10</sub> were above the permissible limit by CPCB in all the monitoring locations.

### 3.3. Air Quality Index (AQI)

The AQI level is in the range of 101-200 (Fig. 4), *i.e.*, the atmosphere is moderately polluted for sampling sites S1 and S2 during most of the time in year, whereas it was found to be a satisfactory level (51-100) for other monitoring sites (S3, S4, S5, S6, S7 and S8). During winter, the AQI level was found higher than the pre-monsoon season, followed by the monsoon season. A significant improvement in AQI level to 'good' level during the lockdown period is observed in all the monitoring sites. During the lockdown, the AQI was significantly reduced in comparison to the previous year (2019) and the reduction percentage was comparably higher in the industrial sites due to the complete shutdown of industries during the lockdown period. The reduction in

AQI level for April - May month are as follows: 57- 42%, 46-34%, 62-42%, 64.8-46%, 68-66%, 37-15%, 35-20% and 40-46% for site S1 to S8, respectively.

### 3.4. Comparison of variation in pollutant concentration during the lockdown in 2020 with a dataset from 2019 and 2021

The concentration of air pollutants like SO<sub>2</sub>, NO<sub>2</sub>, and PM<sub>10</sub> shows a significant reduction during the lockdown. Ground-based observations by Liu *et al.* (2021) around California showed a drop of 31%, 38% and 49% in the concentration of PM<sub>2.5</sub>, NO<sub>2</sub> and CO during the lockdown (March 19-May 7) as compared to pre-lockdown time (January 26-March 18) in 2020. Sulaymon *et al.* 2021 also analyzed a significant improvement in air quality with a decline in concentration of PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub> and CO by 41.2%, 33.1%, 50.6%, and 16.6%, respectively in comparison to the pre-lockdown period in Wuhan city. The most prominent reduction (about 40-60%) was observed for NO<sub>2</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> across India (Singh *et al.* 2020). Around 40-50% improvement in air quality with significant declination by 39%, 52.68% and 60% in the concentration of PM<sub>2.5</sub>, NO<sub>2</sub> and PM<sub>10</sub> was observed in the Delhi region as compared to last year (Mahato *et al.* 2020). The air quality has improved throughout the lockdown by a significant reduction in the concentration of PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>2</sub>, NH<sub>3</sub> and CO by 45.38%, 40.84%, 33.81%, 37.8%, 17.06% and 19.76% from 223 monitoring stations, across the country (Chakraborty *et al.* 2021). Approximately, 20-34%, 24-47% and 32-64% reduction of PM<sub>2.5</sub>, PM<sub>10</sub> and NO<sub>2</sub> were observed during the lockdown in 12 major cities across the globe (Kumari *et al.* 2020). The study by Singh and Chauhan (2020) also observed a promising decline in the concentration of PM<sub>2.5</sub>, NO<sub>2</sub> and AQI over Delhi, Mumbai, Hyderabad, Kolkata and Chennai during the lockdown period (2020) compared with the same period

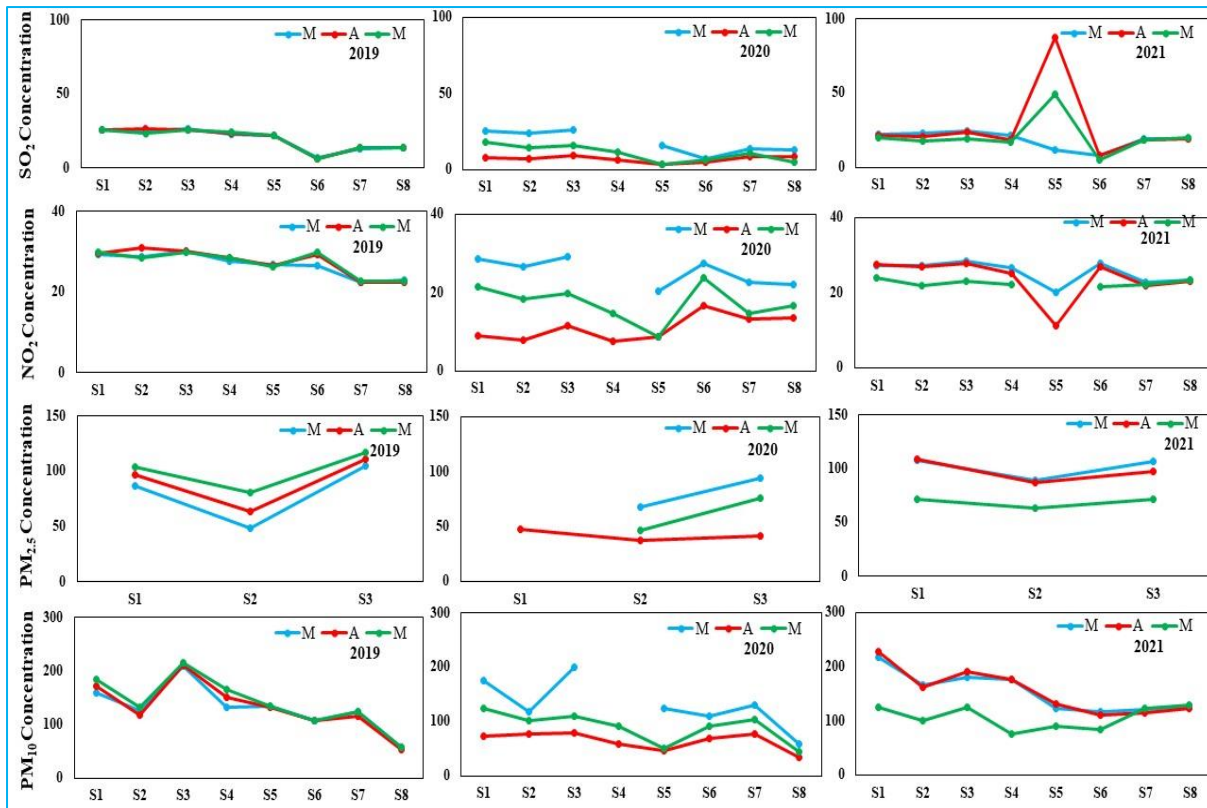


Fig. 5. Variation in concentration of air pollutants during the lockdown period

TABLE 4

Percentage increase in the concentration of pollutants

Site	SO <sub>2</sub>		NO <sub>2</sub>		PM <sub>2.5</sub>		PM <sub>10</sub>	
	April	May	April	May	April	May	April	May
S1	65.5	10.5	67.4	9.79	56.3	-	67.6	1.48
S2	67.8	19.8	70.65	15.75	57.46	26.8	52.81	-0.58
S3	61.5	18.8	58.19	13.47	57.6	5.1	58.63	11.4
S4	67.5	31.4	69.62	34.5	-	-	66.8	-17.06
S5	96.5	92.7	21.58	-	-	-	64.9	45.04
S6	36.3	-11.6	38.18	-9.5	-	-	37.8	-8.1
S7	53.8	43.6	39.56	33.98	-	-	34.05	15.07
S8	55	74.5	41.8	28.86	-	-	71.7	65.04

of the previous year (2019). Significant improvement in air quality from 'poor' category to 'good' category with a decline in concentrations of NO<sub>2</sub>, PM<sub>10</sub>, PM<sub>2.5</sub> by 55.23%, 57.92%, 58.71% in comparison to the pre-lockdown period was evaluated in West Bengal, India (Sarkar *et al.* 2020). In the top 10 major polluted cities of India, a reduction in PM<sub>2.5</sub> was about 39-65% during the lockdown (Roy *et al.* 2021) and a 40-70% reduction is noticed over

the Delhi-National capital region (NCR) in the first week of lockdown as compared to pre-lockdown time (Dhaka *et al.* 2020). It is evident from Table 3 and Fig. 5 that a significant reduction in the concentration of air pollutants like SO<sub>2</sub>, NO<sub>2</sub> and PM<sub>10</sub> in Uttarakhand state during lockdown (March-May, 2020) in comparison to the average concentration before (March-May, 2019). Whereas, the concentration of SO<sub>2</sub>, NO<sub>2</sub>, PM<sub>2.5</sub> and PM<sub>10</sub>



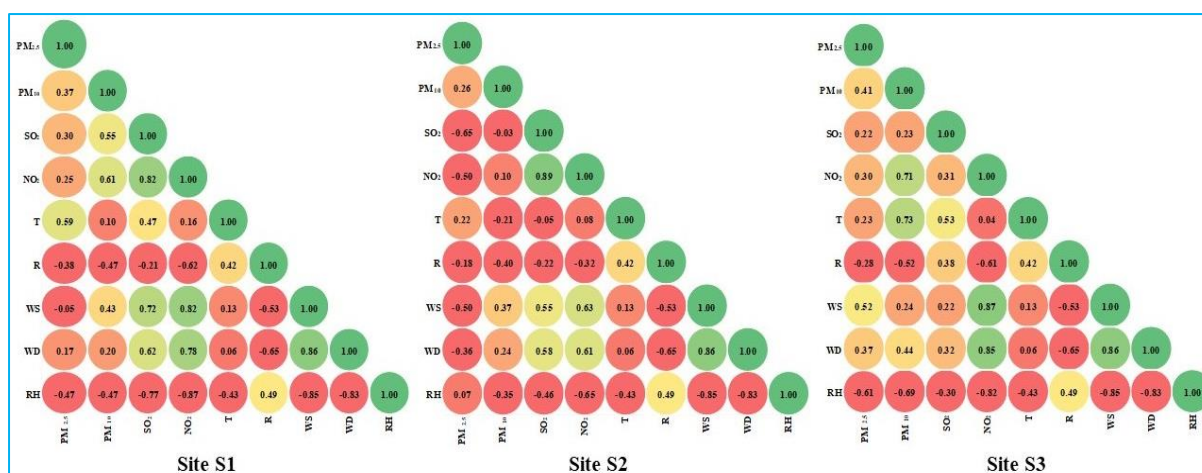


Fig. 6. Pearson correlation matrix showing relationship between concentration of air pollutants and meteorological parameters

TABLE 5

Correlation between concentration of air pollutants

Parameters	PM <sub>2.5</sub>	PM <sub>10</sub>	SO <sub>2</sub>	NO <sub>2</sub>
PM <sub>2.5</sub>	1.00	1.00	1.00	1.00
PM <sub>10</sub>		1.00	0.67	0.34
SO <sub>2</sub>			1.00	0.33
NO <sub>2</sub>				1.00

TABLE 6

Correlation between concentration of air pollutants during pre-lockdown, lockdown, and post-lockdown period

Parameters	2019				2020				2021			
	PM <sub>2.5</sub>	PM <sub>10</sub>	SO <sub>2</sub>	NO <sub>2</sub>	PM <sub>2.5</sub>	PM <sub>10</sub>	SO <sub>2</sub>	NO <sub>2</sub>	PM <sub>2.5</sub>	PM <sub>10</sub>	SO <sub>2</sub>	NO <sub>2</sub>
PM <sub>2.5</sub>	1.00	0.98	0.99	0.92	1.00	0.54	0.46	0.57	1.00	0.94	0.65	0.48
PM <sub>10</sub>		1.00	0.69	0.70		1.00	0.76	0.46		1.00	-0.03	0.57
SO <sub>2</sub>			1.00	0.55			1.00	0.32			1.00	-0.73
NO <sub>2</sub>				1.00				1.00				1.00

shows a significant increase after the lockdown (March-May, 2021) in comparison to lockdown (March-May 2020) as depicted in Table 4 and Fig. 5.

### 3.5. Correlation among the ambient air pollutants

The association between the concentration of various pollutants during the study period was determined by the Pearson correlation coefficient (shown in Table 5). The mean concentration of PM<sub>2.5</sub> is positively correlated (r = 1.00) with the concentration of PM<sub>10</sub>, SO<sub>2</sub> and NO<sub>2</sub>. The average concentration of PM<sub>10</sub> is directly correlated with the concentration of PM<sub>2.5</sub> (r = 1.00), SO<sub>2</sub> (r = 0.67) and NO<sub>2</sub> (r = 0.34). Similarly, the mean concentration of SO<sub>2</sub>

is directly correlated with the concentration of PM<sub>2.5</sub> (r = 1.00), PM<sub>10</sub> (r = 0.67) and NO<sub>2</sub> (r = 0.33) and the mean concentration of NO<sub>2</sub> is also directly correlated with the concentration of PM<sub>2.5</sub> (r = 1.00), PM<sub>10</sub> (r = 0.34) and SO<sub>2</sub> (r = 0.33). Correlation analysis of air pollutants during the pre-lockdown, lockdown, and post-lockdown periods is shown in Table 6. PM<sub>2.5</sub> shows a strong positive relationship with PM<sub>10</sub>, SO<sub>2</sub> and NO<sub>2</sub> during the pre-lockdown and post-lockdown period in comparison to the lockdown period. During the lockdown period, pollutants are positively correlated with each other, whereas SO<sub>2</sub> shows a negative relationship with PM<sub>10</sub> and NO<sub>2</sub> during the post-lockdown period. The correlation between the mean concentration of air pollutants and meteorological

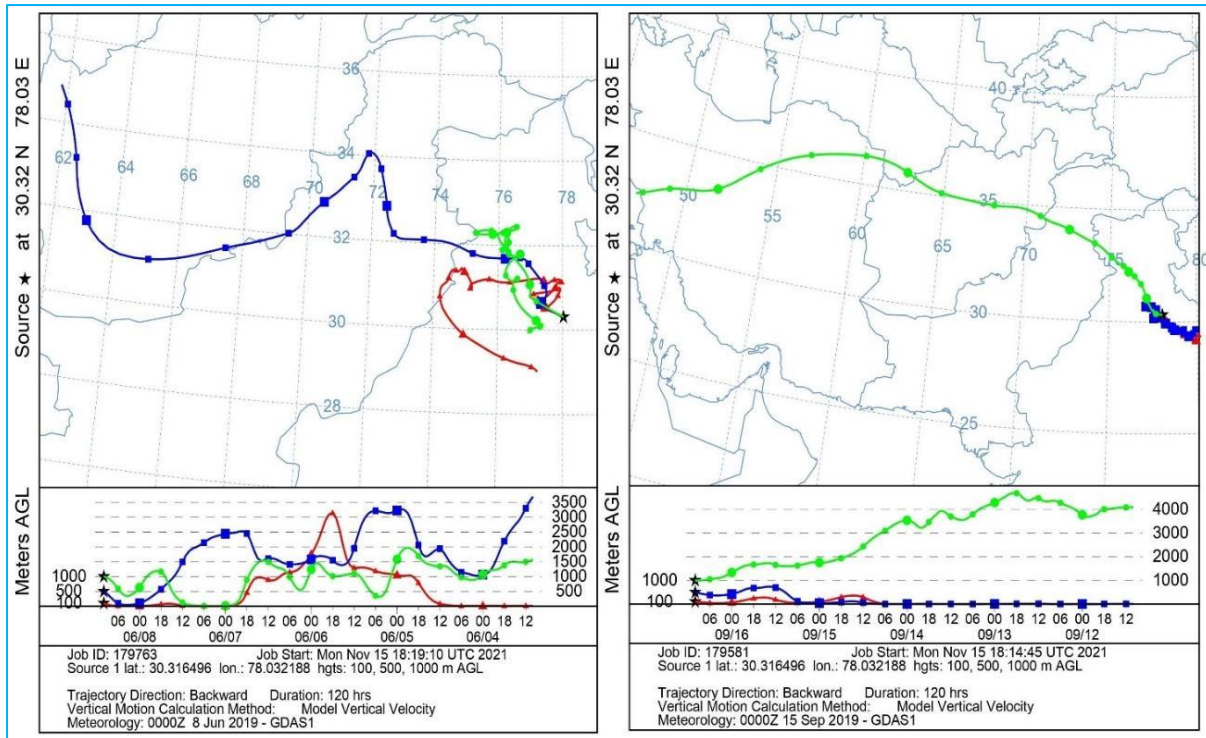


Fig. 7. HYSPLIT model calculated 5-day air mass backward trajectories

parameters for most polluted sites S1, S2, and S3 is shown in Fig. 6. The concentration of air pollutants ( $PM_{2.5}$ ,  $PM_{10}$ ,  $SO_2$  and  $NO_2$ ) shows a positive relationship with meteorological parameters like T, WS and WD whereas they show a negative relationship with R and RH.  $PM_{2.5}$  shows a negative correlation ( $r = -0.50$ ) with WS at sites S1 and S2, which means high winds help in the dispersion of pollutants confined over a place. Winds carry them away from one location to the other, thereby reducing the concentration over this monitoring site. Very Low winds are associated with stagnant or nearly stable conditions over a given location. Negative correlation coefficients of air pollutants with R may be due to the wet deposition by the rain (Bodor *et al.*, 2020; Owoade *et al.*, 2012). Likewise, RH also acts as a natural scrubber that regulates particle movement and then settles down the pollutants (Jayamurugan *et al.*, 2013; Kayes *et al.*, 2019). The positive correlation of pollutants with T may be due to the rise in concentration due to drying up after the washout process by rain (Kayes *et al.*, 2019).

### 3.6. Backward air mass trajectory analysis

In order to delineate the possible source region of pollutants over the most polluted sites, *i.e.*, S1, S2 and S3, we have analyzed 5-day air mass backward trajectories using the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Draxler and Rolph, 2011)

for June and September months of 2019 (highest and lowest polluted months, respectively) at 100 m, 500 m and 1000 m above ground level. Fig. 7 shows the trajectories illustrating the higher mass concentration of pollutants that arrived during the pre-monsoon season and less during the monsoon season. It is found that the air mass travelled from the north-west region, including Northern Pakistan, Punjab and Haryana.

## 4. Conclusions

The emission of air pollutants is influenced by complex variables such as wind, temperature, burning materials, policies, and several other anthropogenic factors. This paper analyzed the annual-seasonal pattern and changes in air pollution before, during, and after the countrywide lockdown induced due to COVID-19. Pollutants like  $SO_2$  and  $NO_2$  are under the prescribed limits of NAAQS while  $PM_{2.5}$  and  $PM_{10}$  are beyond the standards. The COVID-19 pandemic forced us to implement lockdown across the globe, which resulted in a noticeable improvement in air quality. We estimated that COVID-19 control measures resulted in a significant reduction in  $SO_2$ ,  $NO_2$ ,  $PM_{2.5}$  and  $PM_{10}$  emissions by 9.46-86.4%, 20-74.6%, 35.6-62.6%, and 14.7-65%, respectively as compared to the previous year (2019) while a significant increase in the concentration of  $SO_2$ ,  $NO_2$ ,  $PM_{2.5}$  and  $PM_{10}$  by -11.6-96.5%, -9.5-70.65%, to

5.1-57.6 and -17.06-71.7% in comparison to the following year (2021) were shown during the lockdown period. The AQI has improved from a 'satisfactory' and 'moderate' level to a 'good' level in all the selected study sites during the lockdown period in comparison to the pre-lockdown period. With the help of 5-day air mass backward trajectories analysis, it is found that the air mass travelled from the north-west region, from Northern Pakistan, Punjab and Haryana region.

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#### References

- Adelodun, B., Ajibade, F. O., Ibrahim, R. G., Ighalo, J. O., Bakare, H. O., Kumar, P., Eid, E. M., Kumar, V., Odey, G. and Choi, K. S., 2021b, "Insights into hazardous solid waste generation during COVID-19 pandemic and sustainable management approaches for developing countries", *Journal of Material Cycles and Waste Management*, **23**, 2077-2086. doi : <https://dx.doi.org/10.1007%2Fs10163-021-01281-w>.
- Adelodun, B., Ajibade, F. O., Tihamiyu, A. O., Nwogwu, N. A., Ibrahim, R. G., Kumar, P., Kumar, V., Odey, G., Yadav, K. K., Khan, A. H., Cabral-Pinto, M. M. S., Kareem, K. Y., Bakare, H. O., Ajibade, T. F., Naveed, Q. N., Islam, S., Fadare, O. O. and Choi, K. S., 2021c, "Monitoring the presence and persistence of SARS-CoV-2 in water-food-environmental compartments: State of the knowledge and research needs", *Environmental Research*, **200**, 111373. doi : <https://dx.doi.org/10.1016%2Fj.envres.2021.111373>.
- Adelodun, B., Kareem, K. Y., Kumar, P., Kumar, V., Choi, K. S., Yadav, K. K., Yadav, A., El-Denglawey, A., Cabral-Pinto, M., Son, C. T., Krishnan, S. and Khan, N. A., 2021a, "Understanding the impacts of the COVID-19 pandemic on sustainable agri-food system and agroecosystem decarbonization nexus: A review", *Journal of Cleaner Production*, **318**, 128451.
- Awasthi, S., Joshi, P. C., Pandey, C. P., Singh, N. and Nandan, H., 2016, "Long term measurements of ambient air pollutants near a developing industrial township of district Haridwar", *Ind J of Am Sc.*, **12**, 8. doi : <http://www.jofamericanscience.org/>.
- Bodor, Z., Bodor, K., Keresztesi, A. and Szép, R., 2020, "Major air pollutants seasonal variation analysis and long-range transport of PM<sub>10</sub> in an urban environment with specific climate condition in Transylvania (Romania)", *Environmental Science and Pollution Research*, **27**, 38181-38199. doi : <https://doi.org/10.1007/s11356-020-09838-2>.
- Chakraborty, R., Pal, S. C., Ghosh, M., Arabameri, A., Saha, A., Roy, P., Pradhan, B., Mondal, A., Ngo, P. T. T., Chowdhuri, I., Yunus, A. P., Sahana, M., Malik, S. and Das, B., 2021, "Weather indicators and improving air quality in association with COVID-19 pandemic in India", *Soft Computing*. doi : <https://doi.org/10.1007/s00500-021-06012-9>.
- Chauhan, A., Pawar, M., Kumar, R. and Joshi, P. C., 2010, "Ambient air quality status in Uttarakhand (India): A case study of Haridwar and Dehradun using air quality index", *J. of Am. Sc.*, **6**, 9, 565-574.
- Chen, W., Yan, L. and Zhao, H., 2015, "Seasonal Variations of Atmospheric Pollution and Air Quality in Beijing", *Atmosphere*, **6**, 11, 1753-1770. doi : <https://doi.org/10.3390/atmos6111753>.
- Dadhich, A. P., Goyal, R. and Dadhich, P. N., 2018, "Assessment of Spatio-temporal variations in the air quality of Jaipur city, Rajasthan, India", *The Egypt J of Rem Sens and Sp Sc.*, **21**, 173-181. doi : <https://doi.org/10.1016/j.ejrs.2017.04.002>.
- Dandotiya, B., Sharma, H. K. and Jadon, N., 2020, "Ambient Air Quality and Meteorological Monitoring of Gaseous Pollutants in Urban Areas of Gwalior City India", *Environmental claims journal*, **32**, 3, 248-263. doi : <https://doi.org/10.1080/10406026.2020.1744854>.
- Deep, A., Pandey, C. P., Nandan, H., Purohit, K. D., Singh, N., Singh, J., Srivastava, A. K. and Ojha, N., 2019, "Evaluation of ambient air quality in Dehradun city during 2011-2014", *J. Earth Syst. Sci.*, **128**, 96. doi : <https://doi.org/10.1007/s12040-019-1092-y>.
- Deep, A., Pandey, C. P., Singh, N., Nandan, H., Dhaka, S. K., Dimri, A. P. and Purohit, K. D., 2018, "Study of ambient air pollutants over Rishikesh at foothills of north-western Indian Himalaya", *Ind. J. of Rad. & Sp. Phys.*, **47**, 49-60.
- Dhaka, S. K., Chetna, Kumar, V., Panwar, V., Dimri, A. P., Singh, N., Patra, P. K., Matsumi, Y., Takigawa, M., Nakayama, T., Yamaji, K., Kajino, M., Misra, P. and Hayashida, S., 2020, "PM<sub>2.5</sub> diminution and haze events over Delhi during the COVID-19 lockdown period: an interplay between the baseline pollution and meteorology", *Scientific reports*, **10**, 13442. doi : <https://doi.org/10.1038/s41598-020-70179-8>.
- Draxler, R. R. and Rolph, G. D., 2011, "HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) Model", NOAA, Air Resources Laboratory, Silver Spring. doi : <http://www.arl.noaa.gov/ready/hysplit4.html>.
- Gao, H., Wang, J., Li, T. and Fang, C., 2020, "Analysis of Air Quality Changes and Influencing Factors in Changchun during the COVID-19 Pandemic in 2020", *Aerosol and Air Quality Research*, **21**. doi : <https://doi.org/10.4209/aaqr.210055>.
- Giri, A. and Pant, D., 2018a, "Carbon Management and Greenhouse Gas Mitigation", In: Reference Module in Materials Science and Materials Engineering, 312-335. doi : <https://doi.org/10.1016/B978-0-12-803581-8.11041-0>.
- Giri, A. and Pant, D., 2018b, "Inhalation dose due to Rn-222, Rn-220 and their progeny in indoor environments", *Applied Radiation and Isotopes*, **132**, 116-121. doi : <https://doi.org/10.1016/j.apradiso.2017.11.027>.

- Gope, S., Dawn, S. and Das, S. S., 2021, "Effect of COVID-19 pandemic on air quality: a study based on Air Quality Index", *Env. Sc. and Poll. Res.*, **28**, 27, 35564-35583. doi : <https://doi.org/10.1007/s11356-021-14462-9>.
- Goswami, M., Kumar, V., Kumar, P. and Singh, N., 2022, "Prediction models for evaluating the impacts of ambient air pollutants on the biochemical response of selected tree species of Haridwar, India", *Environ. Monit. Assess.*, **194**, 10, 696. doi : <https://doi.org/10.1007/s10661-022-10384-2>.
- Goswami, M., Pant, G., Mansotra, D. K., Sharma, S. and Joshi, P. C., 2021, "Biochar: A Carbon Negative Technology for Combating Climate Change", In: *Advances in Carbon Capture and Utilization, Energy, Environment, and Sustainability*, doi : [https://doi.org/10.1007/978-981-16-0638-0\\_11](https://doi.org/10.1007/978-981-16-0638-0_11).
- Guidelines for the Measurement of Ambient Air Pollutants. Volume-I. CENTRAL POLLUTION CONTROL BOARD Ministry of Environment & Forests Website: <http://www.cpcb.nic.in>.
- Health Effects Institute, 2019, State of global air 2019, Special Report, Boston, MA: Health Effects Institute. doi : <https://doi.org/10.4209/aaqr.210055>. ISSN 2578-6873.
- IEA, 2021, Global Energy Review 2021, IEA, Paris <https://www.iea.org/reports/global-energy-review-2021>.
- Jayamurugan, R., Kumaravel, B., Palanivelraja, S. and Chockalingam, M. P., 2013, "Influence of Temperature, Relative Humidity and Seasonal Variability on Ambient Air Quality in a Coastal Urban Area", *International Journal of Atmospheric Sciences*, 264046,7. doi : <http://dx.doi.org/10.1155/2013/264046>.
- Joshi, P. C. and Semwal, M., 2011, "Distribution of air pollutants in ambient air of district Haridwar (Uttarakhand), India: A case study after the establishment of State Industrial Development Corporation", *Int. J. of Env. Sc.*, **2**, 1.
- Kayes, I., Shahriar, S. A., Hasan, K., Akhter, M., Kabir, M. M. and Salam, M. A., 2019, "The relationships between meteorological parameters and air pollutants in an urban environment", *Global J. Environ. Sci. Manage.*, **5**, 3, 265-278.
- Kumar, S. D. and Dash, A., 2018, "Seasonal variation of air quality index and assessment", *Global J. Environ. Sci. Manage.*, **4**, 483-492. doi : <https://dx.doi.org/10.22034/gjesm.2018.04.008>.
- Kumari, P. and Toshniwal, D., 2020, "Impact of lockdown on air quality over major cities across the globe during COVID-19 pandemic", *Urban Climate*, **34**, 100719. doi : <https://dx.doi.org/10.1016%2Fj.uclim.2020.100719>.
- Liang, L. and Gong, P., 2020, "Urban and air pollution: a multi-city study of long-term effects of urban landscape patterns on air quality trends", *Scientific Reports*, **10**, 18618. doi : <https://doi.org/10.1038/s41598-020-74524-9>.
- Liu, Q., Harris, J. T., Chiu, L. S., Sun, D., Houser, P. R., Yu, M., Duffy, D. Q., Little, M. M. and Yang, C., 2021, "Spatiotemporal impacts of COVID-19 on air pollution in California, USA", *Sc. of the Tot Env.*, **750**, 141592. doi : <https://dx.doi.org/10.1016%2Fj.scitotenv.2020.141592>.
- Mahato, S., Pal, S. and Ghosh, K. G., 2020, "Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India", *Sc. of the Tot Env.*, **730**, 139086. doi : <https://doi.org/10.1016/j.scitotenv.2020.139086>.
- MHA, Ministry of Home Affairs, Government of India, 2020, [https://www.mha.gov.in/sites/default/files/MHAOrderDt\\_30052020.pdf](https://www.mha.gov.in/sites/default/files/MHAOrderDt_30052020.pdf). Accessed date: 15<sup>th</sup> April, 2020.
- Morales-Solís, K., Ahumada, H., Rojas, J. P., Urdanivia, F. R., Catalán, F., Claramunt, T., Toro, A. R., Manzano, C. A. and Leiva-Guzmán, M. A., 2021, "The Effect of COVID-19 Lockdowns on the Air Pollution of Urban Areas of Central and Southern Chile", *Aerosol and Air Quality Research*, **21**. doi : <https://doi.org/10.4209/aaqr.200677>.
- NAAQS Monitoring & Analysis Guidelines Volume-I. Guidelines for the Measurement of Ambient Air Pollutants, 2011. Website: <http://www.cpcb.nic.in>.
- Owoade, O. K., Olise, F. S., Ogundele, L. T., Fawole, O. G. and Olaniyi, H. B., 2012, "Correlation between particulate matter concentrations and meteorological parameters at a site in Ile-Ife, Nigeria", *Ife Journal of Science*, **14**.
- Pant, D., Sharma, V., Singh, P., Kumar, M., Giri, A. and Singh, M. P., 2017, "Perturbations and 3R in carbon management", *Environ. Sci. Pollut. Res.*, **24**, 4413-4432. doi : [10.1007/s11356-016-8143-6](https://doi.org/10.1007/s11356-016-8143-6).
- Pant, P., Lal, R. M., Guttikunda, S. K., Russell, A. G., Nagpure, A. S., Ramaswami, A. and Peltier, R. E., 2019, "Monitoring particulate matter in India: Recent trends and future outlook", *Air Qual. Atm. & Health*, **12**, 45-58. doi : <https://doi.org/10.1007/s11869-018-0629-6>.
- Rao, M. N. and Rao, H. N. V., 1998, "Air pollution", Tata McGraw Hill Publishing Company Limited, New Delhi.
- Roy, S. and Singha, N., 2021, "Reduction in the concentration of PM<sub>2.5</sub> in India's topmost polluted cities: with special reference to post-lockdown period", *Air Quality, Atmosphere & Health*, **14**, 715-723. doi : <https://doi.org/10.1007/s11869-020-00974-9>.
- Sarkar, M., Das, A. and Mukhopadhyay, S., 2020, "Assessing the immediate impact of COVID-19 lockdown on the air quality of Kolkata and Howrah, West Bengal, India", *Env. Develop and Sust.*, 1-30. doi : <https://dx.doi.org/10.1007%2Fs10668-020-00985-7>.
- Sharma, S. K. and Mandal, T. K., 2017, "Chemical composition of fine mode particulate matter (PM<sub>2.5</sub>) in an urban area of Delhi, India and its source apportionment", *Urban Climate*. doi : <https://doi.org/10.1016/j.uclim.2017.05.009>.
- Singh, P. R. and Chauhan, A., 2020, "Impact of lockdown on air quality in India during COVID-19 pandemic", *Air Qual. Atm. & Health*, 1-8. doi : <https://dx.doi.org/10.1007%2Fs11869-020-00863-1>.
- Singh, V., Singh, S., Biswal, A., Kesarkar, A. P., Mor, S. and Ravindra, K., 2020, "Diurnal and temporal changes in air pollution during COVID-19 strict lockdown over different regions of India", *Env. Poll.*, **266**, 115368. doi : <https://dx.doi.org/10.1016%2Fj.envpol.2020.115368>.
- Sulaymon, I. D., Zhang, Y., Hopke, P. K., Zhang, Y., Hua, J. and Mei, X., 2021, "COVID-19 pandemic in Wuhan: Ambient air quality and the relationships between criteria air pollutants and meteorological variables before, during, and after lockdown", *Atm. Res.*, **250**, 105362. doi : <https://doi.org/10.1016/j.atmosres.2020.105362>.
- Vadrevu, K. P., Eaturu, A., Biswas, S., Lasko, K., Sahu, S., Garg, G. K. and Justice, C., 2020, "Spatial and temporal variations of air pollution over 41 cities of India during the COVID-19 lockdown period", *Scientific Reports*, **10**, 16574. doi : <https://doi.org/10.1038/s41598-020-72271-5>.
- WHO, 2020 Coronavirus disease 2019 (COVID-19) Situation Report–63. Available at: [https://www.who.int/docs/default-source/coronavirus/situation-reports/20200323-sitrep-63-covid-19.pdf?sfvrsn=b617302d\\_4](https://www.who.int/docs/default-source/coronavirus/situation-reports/20200323-sitrep-63-covid-19.pdf?sfvrsn=b617302d_4).