A Paper on
Significant Improvement in Ambient Air Quality across Uttarakhand, India due to COVID-19 National Lockdown; Practices to be adapted to restore and maintain this environment quality

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1. Introduction

On 24 March 2020, the Government of India mandated a nationwide lockdown for 21 days, limiting movement of the entire 1.3 billion population of India as a preventive measure against the COVID-19 pandemic in India (https://www.businesstoday.in/current/economy-politics/coronavirus-in-india-21-day-lockdown-begins-key-highlights-of-pm-modi-speech/story/399154.html). Novel coronavirus transmitted rapidly from Wuhan district of China to the entire world and affected several people within a month (Gautam. S, 2020). SARS-CoV-2 affected person was first declared publicly by Gautam and Hens (2020)in Kerala state of India on 30 January 2020. Slowly, the pandemic spread to various states and union territories including the state of Uttarakhand.

In view of the spike in Covid-19 positive patients, Government decided to restrict travel activities,movement ofpeople, vehicles, and suspendedindustrial activities(Zambrano-Monserrate et al., 2020).These lockdowns outcomes have been incredible, as air pollution trend have declined significantly; for instance, greenhouse gas emissions, nitrogendioxide, particulate matter and even water pollution trend during this lockdown period have declined drastically(Zambrano-Monserrate et al., 2020).The decline in the trends of air pollution level have been recently reported in many states across the India like Uttar Pradesh, Delhi, West Bengal, Haryana etc.In Uttar Pradesh, Lucknow, for example, the AQI was significantly reduced and was found to be in the range of 46.64 to 93.11 which falls in Good (050 at Central School and Gomti Nagar) to satisfactory (51100 Lalbagh and Talkatora) AQI range (Srivastava S et al. 2020).As per CSIR-IITR Pre-monsoon 2020 air quality assessment report, in Lucknow the $PM_{2.5}$, PM_{10}, SO_2 and NO_2 concentration were reduced by 35.2%, 44.9%, 18.6% and 27.7% respectively over the previous year.In Kolkata and Howrah, the major air pollutants like $PM_{2.5}$, $PM_{10}$and NO_2 mean concentration from the pre-lockdown phase to during lockdown phase were reduced by ~58.71%, ~57.92% and ~55.23% respectively (Sarkar, M., Das, A., & Mukhopadhyay, S. 2020).

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In Delhi, During the days of lockdown-I there was about 43%decrease in AQI in compare to the first three week of March 2020. About 54%, 49%, 43%, 37% and 31% reductions in NAQI were recorded in Central, Eastern, Southern, Western and Northern regionsof the Delhi respectively(Mahato, S., Pal, S., & Ghosh, K. G. 2020).

As a result of stringent travel restrictions and shutting down of non-essential activities including those of air polluting sectors, air quality improvement has been noted in many towns and cities across the nation including Uttarakhand. A brief analysis and implementation of data generated from ambient air quality monitoring network of Uttarakhand state and findings are summarized in this paper.

In the present study, the variations of Air Quality *Index*(AQI) is analyzed during national lockdowns which were collectedfrom the Uttarakhand state Pollution Control Board (UKPCB) at eight monitoring location in six cities. Data were used to indicatea marked improvement in the levels of AQI due to National Lockdown I, II & III. The lockdown AQI improvement indicate that this coronavirus is considered as a blessing in disguise (Gautam, S. 2020).

2. The study area

The present study has focused on Uttarakhand (30° 4'0.98"N, 79° 1'9.45"E), known for the natural environment of the Himalayas,the Bhabar and the Terai regions. It borders the Tibet Autonomous Region of China to the north; the Sudurpashchim Pradesh of Nepal to the east; the Indian states of Uttar Pradesh to the south and Himachal Pradesh to the west and north-west. The state is divided into two divisions, Garhwal and Kumaon, with a total of 13 districts. Uttarakhand has a total area of 53,483 km^2 (20,650 sq. m),of which 86% is mountainous and 65% is covered by forest.Most of the northern part of the state is covered by high Himalayan peaks and glaciers. According to the 2011 Census of India, Uttarakhand has a population of 101.17 lakh with 69.77% of the population living in rural areas. The population density of the state is 189 people per square kilometre having a 20012011 decadal growth rate of 18.81%.

Currently a total of 8 air monitoring stations are in operation in Uttarakhand (3 in Dehradun, 1 in Kashipur, 1 in Haldwani, 1 in Rishikesh, 1 in Rudrapur and 1 in Haridwar) with a

capacity to monitor and record pollutants twice a week. The locations of the air quality monitoring stations are indicated in Fig. 1.

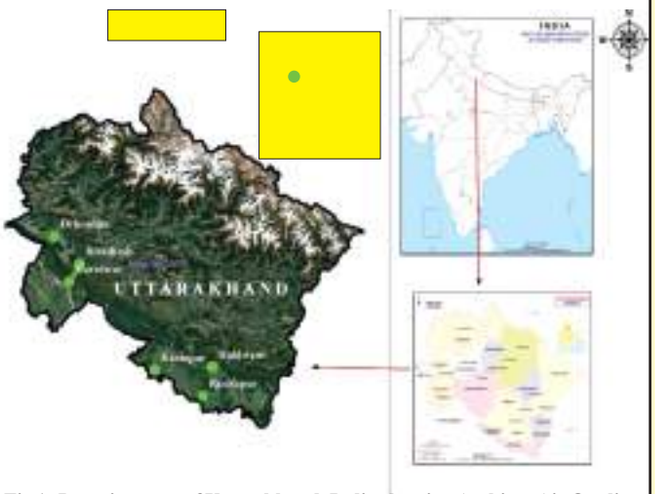

Fig 1: Location map of Uttarakhand, India showing Ambient Air Quality Monitoring Station used for present paper analysis.*(Source: Google earth and ArcGIS)*

3. Air pollution reduction policies across the Uttarakhand state.

`To cope up with the rising pollution in the Uttarakhand, different policy interventions have come up time to time.The Uttarakhand State Pollution Control Board (UKPCB) has always endeavored to strike a rational balance between economic growth and environmental conservation. The UKPCB has been entrusted with the powers and functions under the Air (Prevention and Control of Pollution) Act, 1981 and Environment Protection Act (1986).There are a range of vehicle emission control strategies executed by the government over the decades. These include beginning of unleaded petrol (1998), catalytic converter for fare cars (1995), lessening of Sulphurin diesel (2000) and cutback of benzene content in fuels (2000); initiated CNG for commercial transport vehicles (2001) (Gulia et al., 2018). In January 2016, theGoI has implemented Euro IV emission standard for petroland Euro VI norm for diesel. The BS-VI standard are put into practice for new vehicles since April 2020 respectively. The National Bio-fuels Policy have aimed to convert at least 20% of the diesel and petrol (gasoline) based engines into bio-diesel and bioethanolby 2017 (Purohit and Dhar, 2015). Government of India has also launched the flagship pan India Programme i.e., National Clean Air Programme (NCAP), aimed at reducing Particulate Matter (PM) by 30% nationwide (MoEFCC, 2015). Besides the government efforts, there are several other policies which are incorporated in the action plan prepared by Government of Uttarakhand to mitigate air pollution in three cities i.e., Dehradun, Rishikesh and Kashipur.

4. Methodology

The present study evaluated the improvement in ambient air quality across Uttarakhand due to national lockdown amid the COVID-19 breakout. Fig. 2 shows the overall methodological approach adopted to conduct the study.

4.1 Site Description and Data Collection

The criteria air pollutants are being monitored by the Uttarakhand pollution control board (UKPCB) over 8 monitoring stations in 6 cities where regular monitoring carried out twice a week. The values of $PM_{2.5}$, PM_{10}, SO_2 and NO_2 over 6 cities, one station in each city, were considered for analysis and implementation. Five-time periods viz. 01 April 2019 containing 8 average observations), 2 March 2020 (containing 6 average observations), 3 April 2020 (Lockdown 1 containing 1 average observations), 4 May 2020 (Lockdown 2 containing 1 average observations) and 5 May 2020 (Lockdown 3 containing 2 average observations) were chosen to check the variation of air pollutant concentration. The time period of interest, Lockdown 01 is the ~14days national lockdown period due to the COVID-19 outbreak in India, whereas, Lockdown 02, an ~18 days and Lockdown 03 is 13 days period with given some relaxations. Since the pre-lockdown period includes March (the last month of winter) with lower temperatures, particularly in Northern India compared to the lockdown period (Spring season), last year's concentrations during the analogous periods, April 2019, are also considered for comparing with the 2020 air pollution levels.

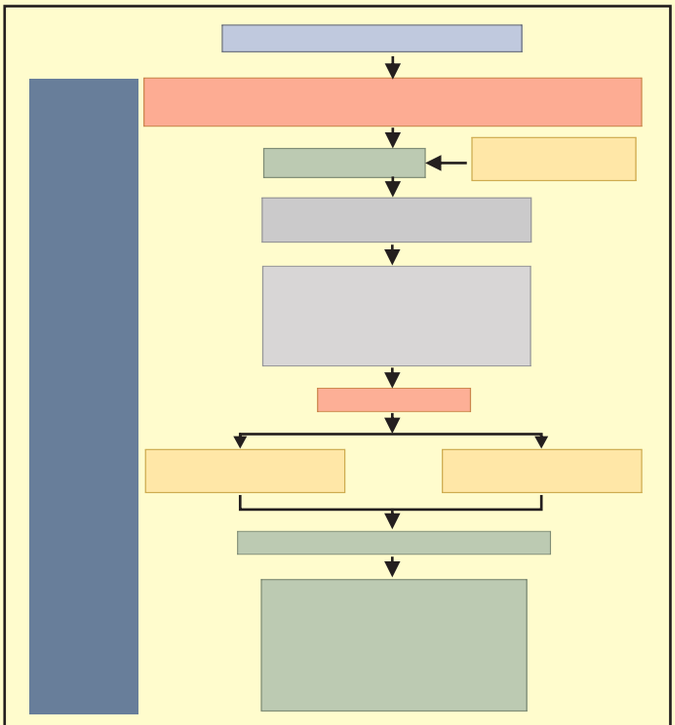

Fig. 2: Overall methodological approach adopted to conduct the study showing improvement in air quality due to national lockdown across Uttarakhand region.

5.0 Result and discussion

The results of the improvement in air quality analysis have been presented in terms of monthly and weekly variations observed in the pollutant concentrations due to the enactment of national lockdown in the selected six cities of Uttarakhand (Fig.3& Fig.4a, 4b, 4c and 4d). Percentage reduction variations in air pollutant concentrations have also been analysed for Uttarakhand cities (Fig.6). Finally, comparison analysis for the levels of air pollutants with wind rose pattern across Uttarakhand cities were carried out, which highlighted the improvement in ambient air quality of the cities due to national lockdowns.

Table 1 represents the Air Quality Index (AQI) values with their color code across Uttarakhand cities before lockdown and during lockdown period. In April 2019, the range of AQI across the stations is lying between 105 and 202. The maximum AQI i.e. 202 was reported at Dehradun air monitoring station while minimum AQI i.e. 105 was reported at Haldwani station. In March 2020 before lockdown period, the AQI concentration was observed more than the stipulate standard values at the all six sites, it ranged from 104, 105, 116, 117, 122 and 196 at Rishikesh, Haldwani, Kashipur, Rudrapur, Haridwar and Dehradun respectively. Further, during lockdown-1 it was observed that AQI varied from 54, 61, 71, 72, 72 and 75 at Rishikesh, Haridwar, Haldwani, Rudrapur, Dehradun and Kashipur respectively and during lockdown-2 lowest AQI was observed at Haridwar among all Uttarakhand cities i.e., 32 which was in Good AQI ranking zone. In lockdown-3, AQI was increased slightly to 81, 82, 83, 95, 99 and 163 at Haldwani, Kashipur, Rishikesh, Haridwar, Rudrapur and Dehradun respectively due to some relaxation given by Uttarakhand government (Fig 3).

Table1. City wise Air Quality Index (AQI) with their colour code during lockdown and before lockdown period

Air Quality Index (AQI)					
Name of City	April-19	March-20	Lockdown-1	Lockdown-2	Lockdown-3
Dehradun	202	196	72	82	163
Rishikesh	133	104	54	64	83
Haridwar	121	122	61	32	95
Dehradun	111	116	75	78	82
Rishikesh	118	117	72	78	99
Haridwar	105	105	71	69	81

(0 - 50) (51 - 100) (101 - 200) (201 - 300)

Increase in Air Quality Index (AQI) is proportional to worst air pollution

Table 2 : represents the monthly concentration and lockdown wise concentration of air pollutants across Uttarakhand cities before lockdown and during lockdown period. The monthly average concentration values of air pollutants varied spatially. The monthly average concentration range of PM_{10} across the six monitoring stations is lying between 31.87µg/m^3 and174.04µg/m^3. The PM_{10} maximum concentration i.e. 74.04µg/m^3 was monitored at Dehradun during March 2020 and lowest concentration i.e. 31.87µg/m^3 was monitored at Haridwar during lockdown-2. Among all the stations, in Haridwar PM_{10} concentration showed highest reduction variability from 131.88µg/m^3 in April 2019 to 31.87µg/m^3 in lockdown-2. In March 2020, the monthly average concentration of $PM_{2.5}$ across Dehradun city was monitored above standard value i.e. 88.94µg/m^3, reduced to 28.72µg/m^3 in lockdown-2. Before lockdown, the monthly average concentration range of SO_2 across the six monitoring stations is lying between 6.45µg/m^3 to 25.94µg/m^3, maximum concentration was observed at Dehradun i.e. 25.94µg/m^3 while minimum concentration was at Haldwani. During lockdown-1 in Dehradun, it was reduced to 6.9µg/m^3 and in Haldwani reduced to 2.5µg/m^3. There was highest percent reduction in SO_2 concentration in Haridwar i.e. 98% from 16.05µg/m^3 to 1.0µg/m^3. Further for NOx air pollutant, before lockdown maximum concentration was monitored at Dehradun i.e. 30.3 µg/m^3 and minimum concentration was at Haridwar i.e. 20.41 µg/m^3 Due to enactment of lockdown, it was reduced to 8.7µg/m^3 in Dehradun and 8µg/m^3 in Haridwar.

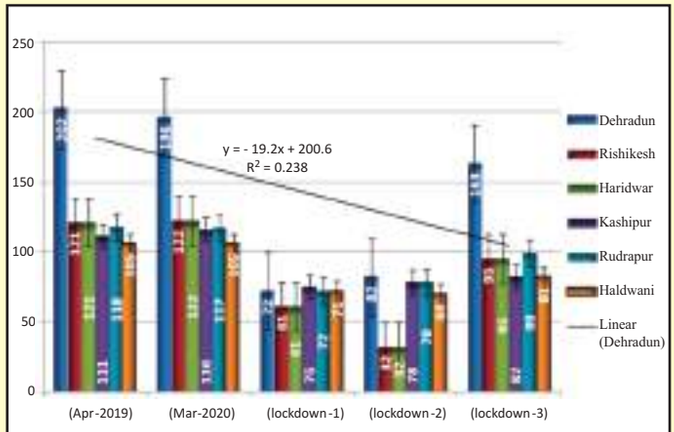

Fig 3 : Variability in Air Quality Index (AQI) across Uttarakhand region during lockdown and before lockdown period.

Table 2 : Monthly and lockdown wise concentration of air pollutants across Uttarakhand cities

Sites	Time	PM_{10}	$PM_{2.5}$	SO_2	NO_2	AQI
Dehradun	April-19	167.16	90.62	25.7	30.3	202
	March-20	174.04	88.94	25.94	29.13	196
	Lockdown-1	71.86	28.72	6.9	8.7	72
	Lockdown-1	81.06	49.12	8.54	10.34	82
	Lockdoqn-3	98.2	79.28	12.9	16.9	163
Haridwar	April-19	131.88	DNA*	22.4	26.54	121
	March-20	123.32	DNA*	16.5	20.41	122
	Lockdown-1	61.28	13.5	1	8	61
	Lockdown-2	31.87	DNA*	3.04	11.83	32
	Lockdown-3	38.03	DNA*	2.9	8.11	38
Kashipur	April-19	115.78	DNA*	13.45	22.35	111
	March-20	123.25	DNA*	13.35	22.16	116
	Lockdown-1	74.92	DNA*	8.2	12.8	75
	Lockdown-2	77.68	DNA*	9.2	13.5	78
	Lockdown-3	94.75	DNA*	9.46	14.31	95
Rishikesh	April-19	150.2	DNA*	23.73	28.37	133
	March-20	105.27	DNA*	22.72	26.82	104
	Lockdown-1	53.55	DNA*	5.56	6.58	54
	Lockdown-2	63.55	37.5	6.4	8.66	64
	Lockdown-3	81.5	DNA*	9.9	12.5	82
Rudrapur	April-19	126.69	DNA*	13.44	22.35	118
	March-20	125.76	DNA*	13.48	22.08	117
	Lockdown-1	72.46	DNA*	8.4	13.02	72
	Lockdown-2	78.18	DNA*	8.86	13.85	78
	Lockdown-3	99.12	DNA*	9.79	15.01	99
Haldwani	April-19	107.4	DNA*	6.45	29.44	105
	March-20	108	DNA*	7.49	27.53	105
	Lockdown-1	71.3	DNA*	2.5	15.43	71
	Lockdown-2	68.8	DNA*	2.73	18.15	69
	Lockdown-3	80.65	DNA*	4	23.8	81

DNA* Data Not Available

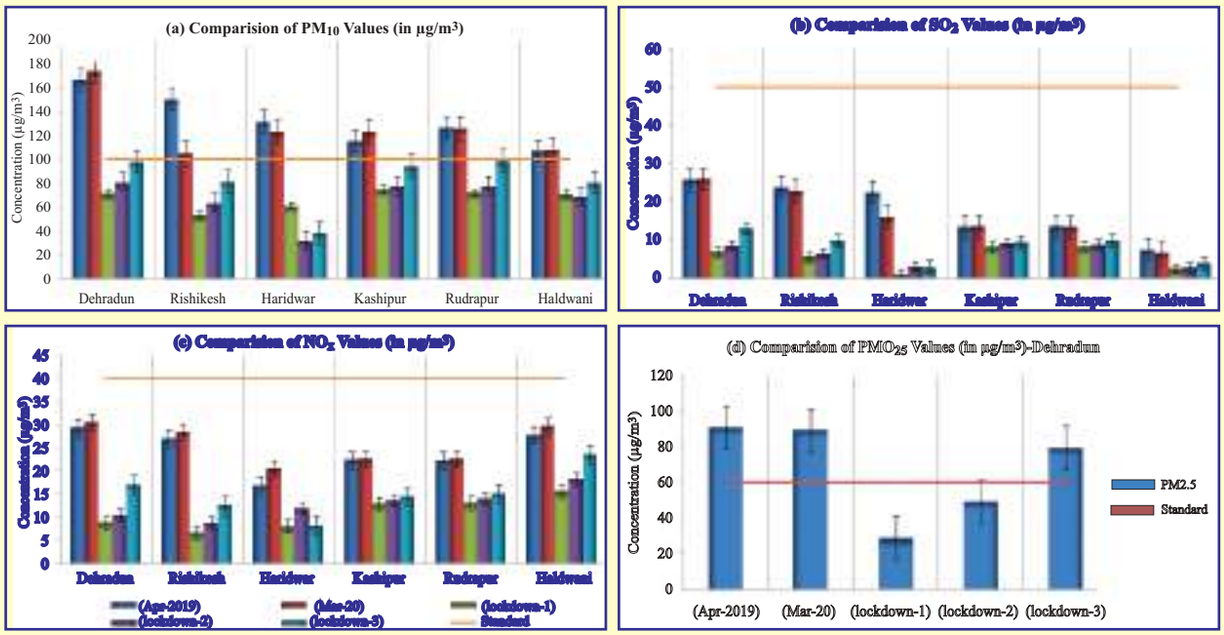

Fig 4 : Spatial Trend analysis of pollutant concentration of (a) PM_{10} (b) SO_2, (c) NO_2 and (d) $PM_{2.5}$ showing comparison before lockdown and during lockdown across Uttarakhand.

Least human activities in the April and May month due to the enactment of lockdowns have cleaned up the air across the Uttarakhand cities. The data which collated Air Quality Index (AQI) level across six centres: Dehradun, Rishikesh, Haridwar, Kashipur, Haldwani and Rudrapur shows that the AQI level in each centre was between 50 and 100. After enactment of these lockdowns in Uttarakhand city, air pollution level has witnessed significant reduction of air pollutants (Fig 5 & Fig 6). During these lockdown period PM_{10}, $PM_{2.5}$, NO_x and SO_2 concentration have shown notable declining trend. Table 3 represents the percent reduction value for the air pollutants during this lockdown period. The average concentration of $PM_{2.5}$ before lockdown was higher in comparison to the concentration during lockdown I, II and III. The $PM_{2.5}$ concentration in Dehradun was reduced by 71% in lockdown I, 68% in Lockdown II and 12% in lockdown III. Among the pollutants, PM_{10} and SO_2 exhibit the most reduction to 75% and 98% respectively, in particular, over Haridwar, Rishikesh and Dehradun during the lockdown I, II and III. Considering all pollutants, Haridwar among all stations experienced the highest percent reduction which varies from 75% for PM_{10}, 57% for NO_x to 98% for SO_2 and may be attributed to reduced traffic density and fuel consumption. The NO_x levels here have also gone down by 73% in Dehradun, 74% in Rishikesh, 43% in Kashipur, 41% in Rudrapur and 46% in Haldwani (Fig 8). The SO_2 level changes from 38% to 98% in lockdown I, 35% to 84% in lockdown II and 28% to 84% in lockdown III (Fig 5).

In particular the air quality has improved considerably in Garhwal region especially in Dehradun in the past April and May month. In April last year, AQI of Dehradun was 202 but the AQI in the capital city in the corresponding month this year was just 72. Dehradun AQI was also 196 in March before the lockdown. In Rishikesh AQI was 133 in April 2019 which was reduced to 54 and 64 in lockdown I and II respectively, but it increased to 83 in lockdown III due to some relaxations given by government like E-commerce was allowed in non-essential items in green zone and also in orange zones, all goods traffic was permitted, buses could operate with up to 50% seating capacity etc. In Kashipur AQI was 122 in March 2020 which is reduced to 61 and 32 in lockdown I and II respectively, while in lockdown III it was shown as 95 AQI. In Rudrapur, AQI was reduced from 117 (Before lockdown) to 72 (After lockdown). In Haldwani, found the same AQI reduction that is from 105 to 69. Among all the centres, Haridwar showed the highest reduction to 74% in lockdown II i.e., AQI reduced to a good region (0-50) (Fig 6).

Table 3: Percent reduction in air pollutants concentration amid lockdowns in six cities of Uttarakhand as compared with the regular trend

Parameters / Cities	Lockdown-1				Lockdown-2				Lockdown-3			
	PM_{10}	SO_2	NO_X	AQI	PM_{10}	SO_2	NO_X	AQI	PM_{10}	SO_2	NO_X	AQI
Dehradun	58%	72%	73%	64%	58%	67%	65%	59%	43%	50%	43%	20%
Rishikesh	58%	76%	74%	59%	51%	72%	68%	52%	38%	57%	56%	27%
Haridwar	53%	98%	57%	50%	75%	84%	36%	74%	70%	84%	56%	21%
Kashipur	38%	38%	43%	33%	35%	38%	40%	30%	20%	30%	36%	26%
Rudrapur	43%	38%	41%	39%	38%	35%	38%	39%	21%	28%	32%	16%
Haldwani	35%	64%	46%	32%	36%	61%	36%	34%	25%	43%	18%	23%

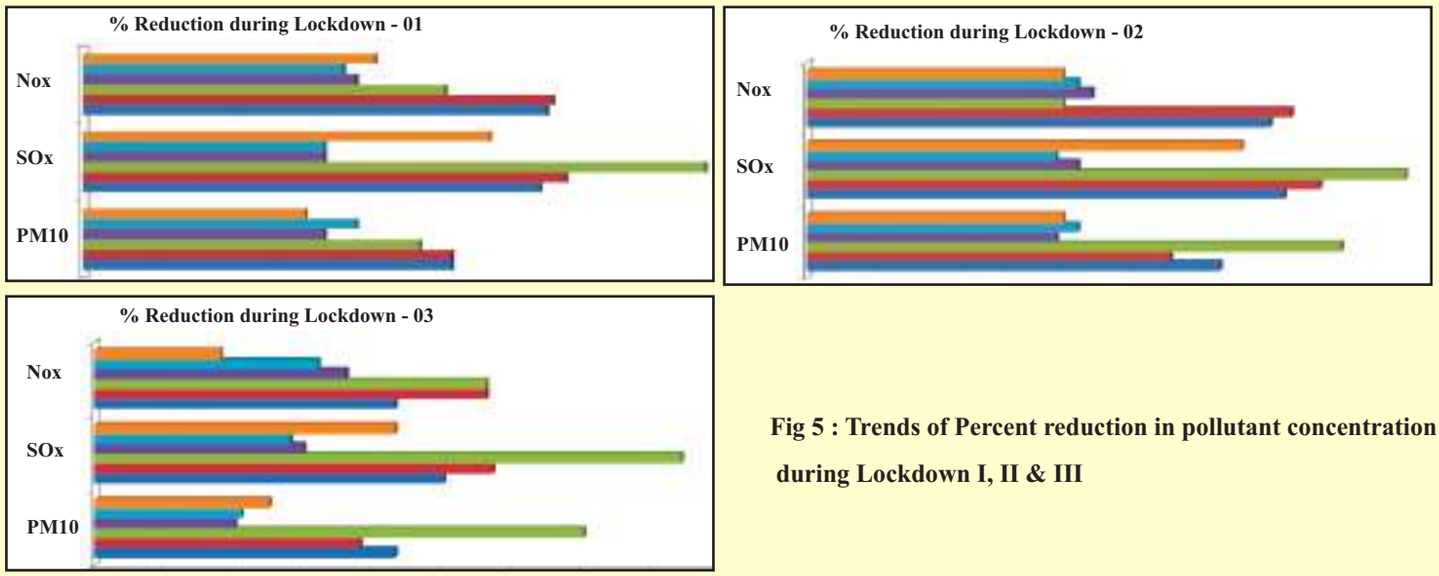

Fig 5 : Trends of Percent reduction in pollutant concentration during Lockdown I, II & III

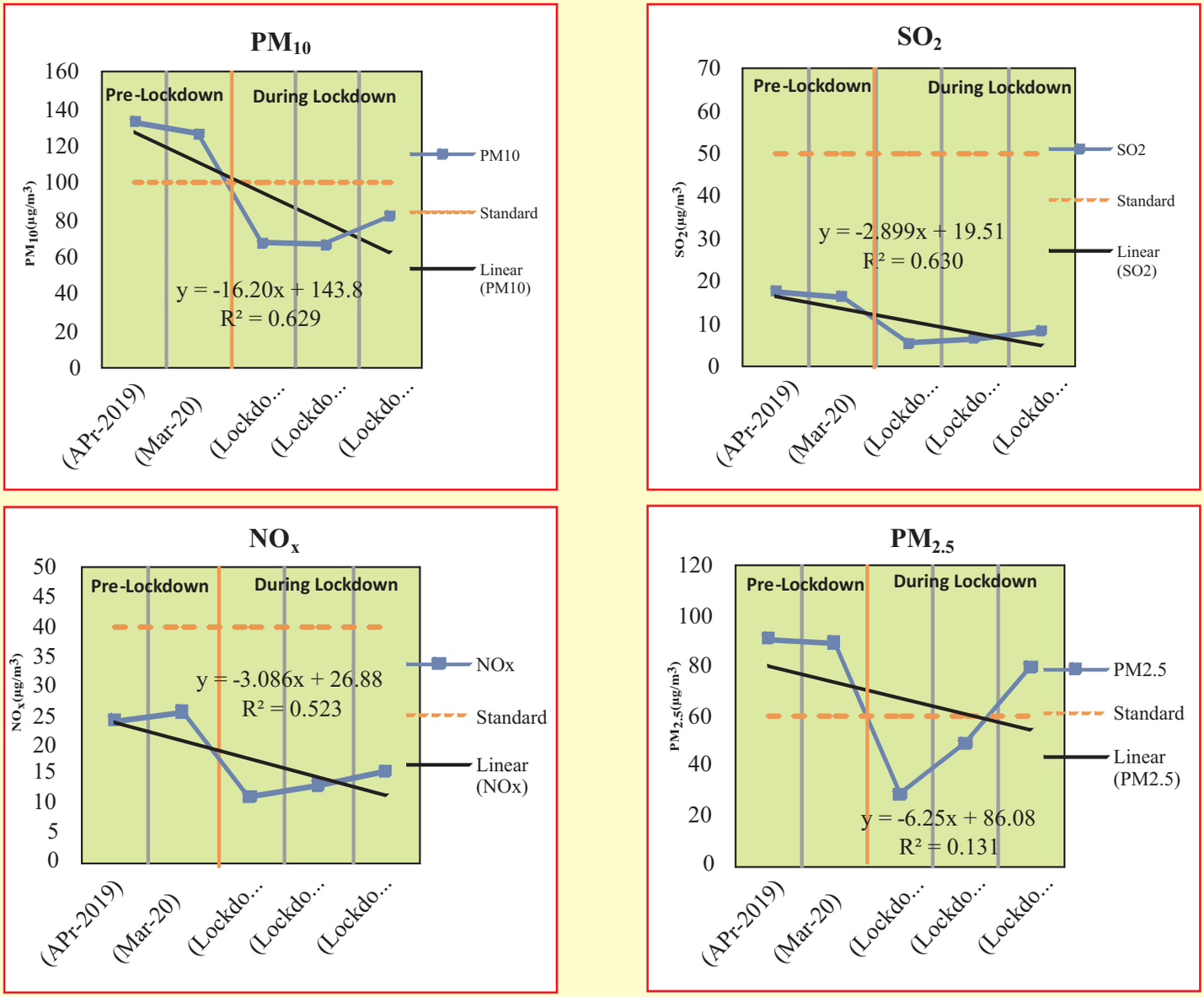

Fig 6: Trend of 24hourly average pollutant concentration of (a) PM_{10} (b) SO_2, (c) NO_x and (d) $PM_{2.5}$ showing comparison before lockdown and during lockdown across Uttarakhand.

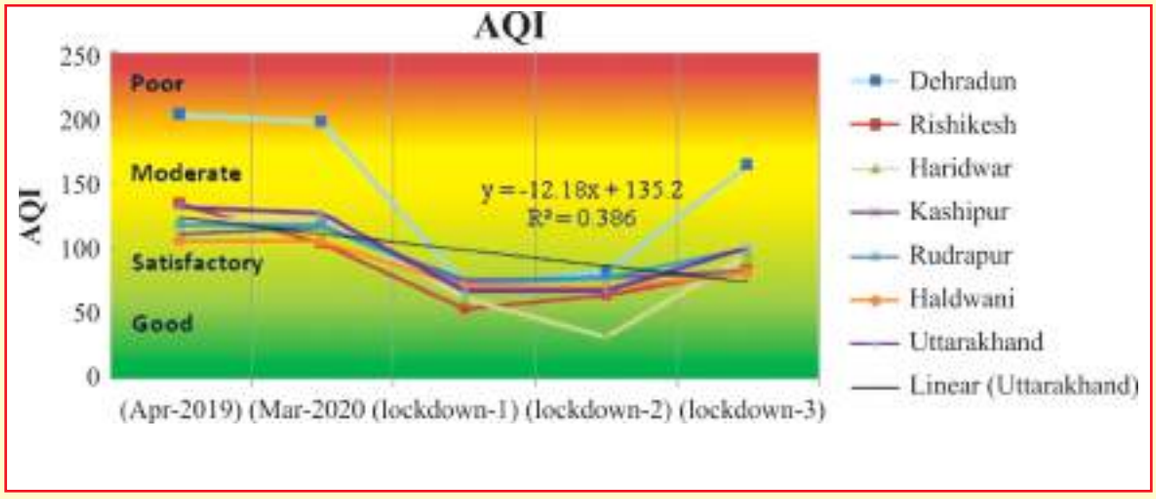

Fig 7: Monthly and lockdown wise AQI variability across Uttarakhand region

Earth null school-based maps are used to show the comparison in level of air pollution between April 2019 and April 2020. In April 2019, the concentration of both $PM_{2.5}$ and PM_{10} which are shown in red and orange color on the map was very high (Fig. 8a)due to the thermal power stations, industrial activities, transportation and construction etc. while in April 2020, the atmospheric concentration of particulate matters is substantially very low than the previous year (Fig.8b), due to restricted activities likelow emission from vehicles, low active construction sites and no industrial emissions during this complete lockdown.

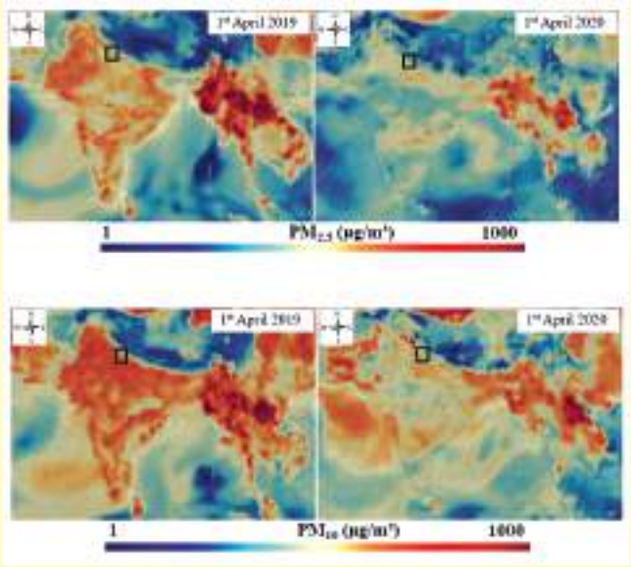

Fig 8: Particulate matter (a) $PM_{2.5}$ (b) PM_{10} concentration change from 1st of April 2019 to 1st of April 2020.

WRPLOT based wind rose diagram has been plotted for Dehradun, Haldwani, Haridwar, Kashipur and Rudrapur stations throughout the lockdown period (Fig 9). Fig 9 represents the annually and lockdown wise monthly variability in wind speed and wind direction over Dehradun monitoring station. Wind speed and wind direction play a crucial role in the transport as well as the magnitude of the concentration of ambient air pollutants across monitoring stations (Soni et al. 2018). The annual wind rose diagram of Dehradun depicted that prevailing wind direction across Dehradun was dominated by North-Easterlies with average speed fall in the range of 1-2 m/s. Before lockdown period, the transport from North West could enhance the air pollution over to Dehradun and upto some extent over other regions like Rishikesh and Haridwar. It indicates that during lockdown and before lockdown period air pollutant majorly particulate matter concentration is coming from forest fire hotspot like Almora and Tehri Garhwal region (Fig 9). While other stations like Haridwar and Rudrapur were characterized by lowest concentration particulate matter and winds predominantly coming from North direction (Fig 9). Haldwani and Kashipur were dominated by winds coming from North North-East direction (Fig 9). Over Dehradun station, we could see that the wind speeds between 1.0 2.0 m/sec were most common. Lastly, the Dehradun and Rudrapur season exhibited

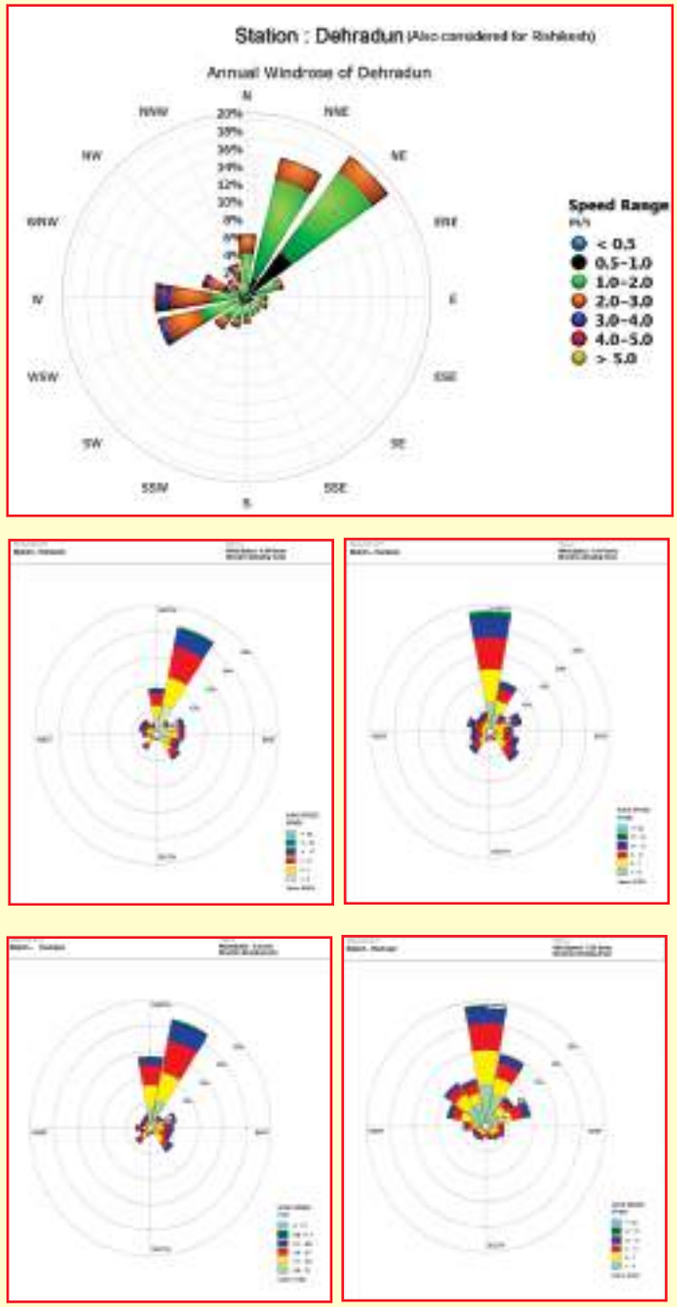

Fig 9: WRPLOT based wind rose diagram of (a) Dehradun, (b) Haldwani, (c) Haridwar, (d) Kashipur and (e) Rudrapur showing wind direction and wind speed.

large variability in the prevailing wind directions and the wind speeds. It can also be observed that the prevailing wind speeds in Dehradun were lower than other stations, thus favouring stagnant atmosphericconditions and higher levels of particulate matter.

6. Conclusion

This study analyses the variability in the concentration of PM_{10}, $PM_{2.5}$, NO_x and SO_2 and AQI at six stations in the Uttarakhand state during lockdown and before lockdown period. It was observed that before lockdown the particulate matter concentration at all the stations had violated the CPCB standard. The data shows that during April 2019 and initial days of March

2020 had more pollution as traffic movement get maximum sluggishness, jam in all routes in Dehradun, high fuel consumptions and more construction activities. Sharp increase in number of vehicle plying, duration of idling increases highly,more domestic fuel burns, open waste burning, construction activities and industrial emissions are suppose to cause more emission of particulate matter. During lockdown period across all stations of Uttarakhand state, this was for the first time that we have monitored so low AQI levels. It was also evident that the lockdown days were less polluted in case of particulate matter (PM_{10}& $PM_{2.5}$), Sulphur dioxide (SO_2) and Nitrogen oxide(NO_x) and it may be attributed that Non-appearance of motor vehicles, close down of industries and lack of influx of tourists are the main factor that played a strong role in improving ambient air quality levels.

The results will attract the attentiveness of the Government to consider on how to strictly minimize automobile and industrial emission sources to improve ambient air quality which will help to encourage better public health in the State.

7 : Solutions / Policies to be adopted to maintain these air improvements

There are several opportunities given by these national lockdowns to ameliorate the policy measure to reduce pollution impacts on environment with stabilizing economy too. It was underlined here that this lockdown has taught us to understand nature has its own power to restore its quality. To restore balance between environment and economy, it is necessary to support new environment policies for our better future. There are some achievable solutions or policies which we need to implement in action like a quick reduction of fuel based consumption to green technologies based energy production, fossil free transportation should be facilitated, more investments in the production and distribution of biogas, promote innovative, resource-efficient solutions with substantial capacity for both public transport and cycling, ban open field burning of agricultural harvest residue and waste and forest residue, preventive measure should be taken to avoid uncontrolled wildfires, adaptation of clean technology in a very phased manner, stop deforestation around pollution hotspot area

It can be concluded that the lockdown ambient air quality trend line taught a lesson to all the stakeholders belongs to scientific, educational, policy-decision, and politics how to restore the future air quality scenarios and which sectors need to be controlled and how much (Wang et al., 2020).

8. Acknowledgement

The UKPCB acknowledges the Earth null school for the free use of particulate matter data and maps.

All employees of Board engaged in generation, compilation interpretation of data are acknowledged.

9. Reference

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