

# IMPACT OF FOREST FIRE EMISSIONS ON AIR QUALITY OVER WESTERN HIMALAYA REGION

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### ABSTRACT

Emissions from forest fires give out huge amounts of greenhouse gases into the atmosphere degrading the surrounding air quality. Climate change results in prolonged summer days and less precipitation thus increasing fuel accumulation facilitating recurring forest fires in the Western Himalayan regions. Most of the forest fire cases are human ignited that damaging the forest irreparably. This study attempts to analyse the impact of the forest fire events on the tropospheric concentrations of five major gaseous pollutants aerosols, Carbon Monoxide (CO), Nitrogen Dioxide (NO<sub>2</sub>), Sulphur Dioxide (SO<sub>2</sub>) and Formaldehyde (HCHO). A clear increase in daily average of the air pollutants considered in the study was observed as the number of forest fires were also increasing. The gases responded inversely with precipitation. Precipitation washed away majority of the air pollutants. The high-resolution air quality data were retrieved from the Google Earth Engine platform using Sentinel 5 Precursor datasets, daily active fire points from the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument of Suomi National Polar-orbiting Partnership (SNPP) and daily precipitation data from CHIRPS Daily Version 2.0 Final. Four out of five gases i.e., CO, aerosols, NO<sub>2</sub>, HCHO pollutants gave moderate to high correlation values with the forest fire incidences. Air pollutants responded inversely with the precipitation pattern.

### 1. INTRODUCTION

Western Himalayan region is an ecologically fragile environment. There is a great variation in altitude which renders different vegetation types like alluvial grasslands, subtropical forests, conifer mountain forests and alpine meadows (Tewari et al., 2017). The variation in height and sharp seasonal contrasts speeds up the triggering by climate change which intensely disturb the ecosystem functioning and human environments. Forest fires have become a periodic event for the Himalayan states and the changing climate is making it even worse. Climate change is causing more summer days and less precipitation, making the vegetation dry and conducive to large forest fires. Which results in longer fire seasons and reductions in carbon stocks (Jolly et al., 2015). One of its severe consequences is the deterioration of the regional air quality. Forest fire emits a large amount of greenhouse gases like Carbon Dioxide, Sulphur Dioxide, Nitrogen Dioxide, etc. these gases pose a direct threat to human health and to the climate at large. Most of the fire incidences are intentional by human for agricultural residue burning, shifting cultivation, seed and flower collection, better growth of grass (Satendra and Kaushik, 2014). Major cause for recurrent fire events is the regional domination of fire prone tree species like Chir Pine which are dominantly found in Jammu and Kashmir, Himachal Pradesh and most of its forest cover in Uttarakhand (Fulé et al., 2021). Forests are the major source and sinks of carbon. Recurrent forest fires releases tonnes of harmful gases into the atmosphere. Aerosol particles in the atmosphere both scatter and absorb incoming solar radiation, get deposited on the leaf surface, affecting plant productivity (Izuta, 2017).

Sulphur Dioxide (SO<sub>2</sub>) is the main component of acid rain that destroys foliage tissue and acidify water bodies. In humans it can create respiratory illness and aggravate existing heart and lung

conditions. SO<sub>2</sub> creates radiative forcing by the formation of sulphate aerosols.

High NO<sub>2</sub> concentration affects the foliage by decreasing the growth. CO contributes indirectly to climate change as it is a precursor of tropospheric ozone. It does not affect plants as it is rapidly oxidised to form carbon dioxide an important input for photosynthesis. Exposure to carbon monoxide cause dizziness, confusion, and irritability. Formaldehyde is an intermediate gas in nearly all oxidation chains of Non-Methane Volatile Organic Compounds (NMVOC), leading ultimately to CO<sub>2</sub>. When wild animals are exposed to this, it can make them sick, affect their appearance, breeding behaviour, and reduce their life spans (Duong et al., 2011).

Ground monitoring resources especially in the Western Himalayan regions have spatial gaps which can be solved by using satellite data that can fill in the information on air quality in areas without ground monitoring. Many satellites can give information on criteria air pollutants and greenhouse gases for example. When selecting satellite data to address specific air quality issues, accuracy, spatial and temporal resolution are important considerations. Several studies and monitoring stations have documented a rapid increase in the concentration of air pollutants in the Himalayan ranges (Giri et al., 2008; Putero et al., 2014; Xu et al., 2009).

Air pollution pose a threat to Himalayan region, affecting its ecosystem, health of inhabitants, the cryosphere and many more. It is the emission of these harmful gases and their impact on the vegetation and climate that necessitate special attention. In this study we aim to analyse the impact of forest fires incidences on different air quality parameters- tropospheric concentration of aerosol, NO<sub>2</sub>, SO<sub>2</sub>, CO, HCHO from Sentinel 5P for the years

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2019, 2020 and 2021 for Western Himalayan regions- Ladakh, Jammu and Kashmir, Himachal Pradesh, Kumaon and Garhwal. We have also analyzed the response of different air quality parameters with the precipitation pattern. We have also done the correlation analysis of the fire incidences with the air quality parameters.

## 2. STUDY AREA

The study area comprises 5 regions of western Himalaya - Uttarakhand further divided into Kumaon and Garhwal, Himachal Pradesh and the union territories of Jammu and Kashmir and Ladakh. The western Himalaya includes the Zaskar Range, Pir Panjal Range, Siwalik Range, Ladakh Range, Dhauladhar Range and the Great Himalaya and parts of the Shivalik Range. The elevation of the study area ranges from 180 to 7600m. According to the (ISFR, 2019), in Uttarakhand the average annual rainfall is 1,500 mm and the annual temperature varies from 0°C to 43°C. 63.41% of the area is under forests. In Himachal Pradesh, the tree growth is minimal due to harsh conditions. The average annual rainfall is about 1,800 mm. The temperature varies from sub-zero to 35°C. Forests cover 24.61% of the state's geographical area.

For Jammu & Kashmir and Ladakh the average annual rainfall varies from about 600 mm to about 800 mm and the average annual temperature from sub-zero to 40°C. Forests cover 56.65% of the geographical area of these two union territories. The Western Himalaya consists of different forest types like alpine forests, semi-evergreen, deciduous, sub-tropical broad-leaved hill forests, subtropical pine forests and sub-tropical montane temperate forests.

## 3. DATA AND METHODOLOGY

For analysis, fire seasons starting from February 1 to June 30 of three years 2019, 2020 and 2021 were considered. Google Earth Engine (GEE) was used to retrieve the daily air quality and precipitation data.

The VIIRS 375 m thermal anomalies / active fire product from the VIIRS sensor aboard the joint NASA/NOAA Suomi NPP was used for analysis of temporal and spatial distribution of fire events.

Data for entire fire season with all low, nominal and high level of confidence for fire detection, for the specified years was taken and clipped for those 5 regions. Air quality data was taken from SENTINEL 5P satellite. It is focused on air quality and composition-climate interaction with the main data products being O<sub>3</sub>, NO<sub>2</sub>, SO<sub>2</sub>, HCHO, CH<sub>4</sub>, and UVAI with a spatial resolution of 1.11km. For analysis daily average of aerosols, Carbon Monoxide, Formaldehyde, Nitrogen Dioxide and Sulphur Dioxide were taken for all the 5 regions.

Daily precipitation data were obtained from CHIRPS Daily: Climate Hazards Group Infrared Precipitation with Station Data (Version 2.0 Final). This provides more than 30 years of quasi-global rainfall datasets having a spatial resolution of 0.05°. The precipitation data was then combined with the fire points and air pollutant data of those 5 western Himalayan regions. The air pollutants concentration was multiplied by 100000 for all the gases except AI and CO.

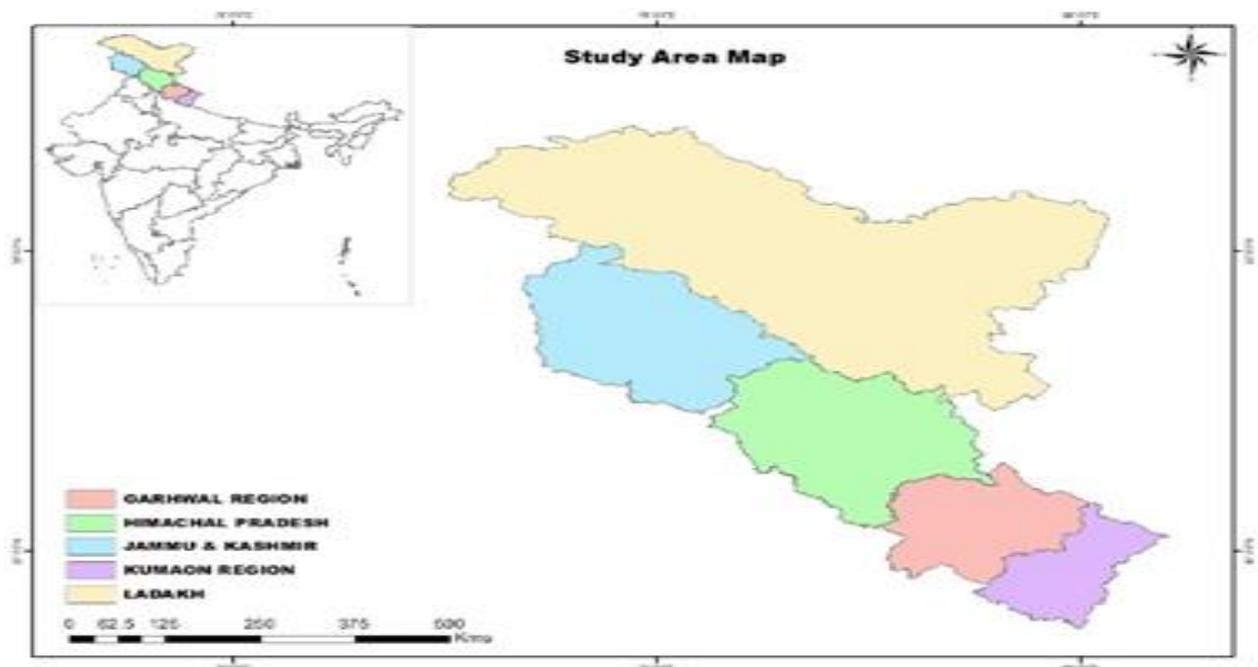


Figure 1. Study Area Map

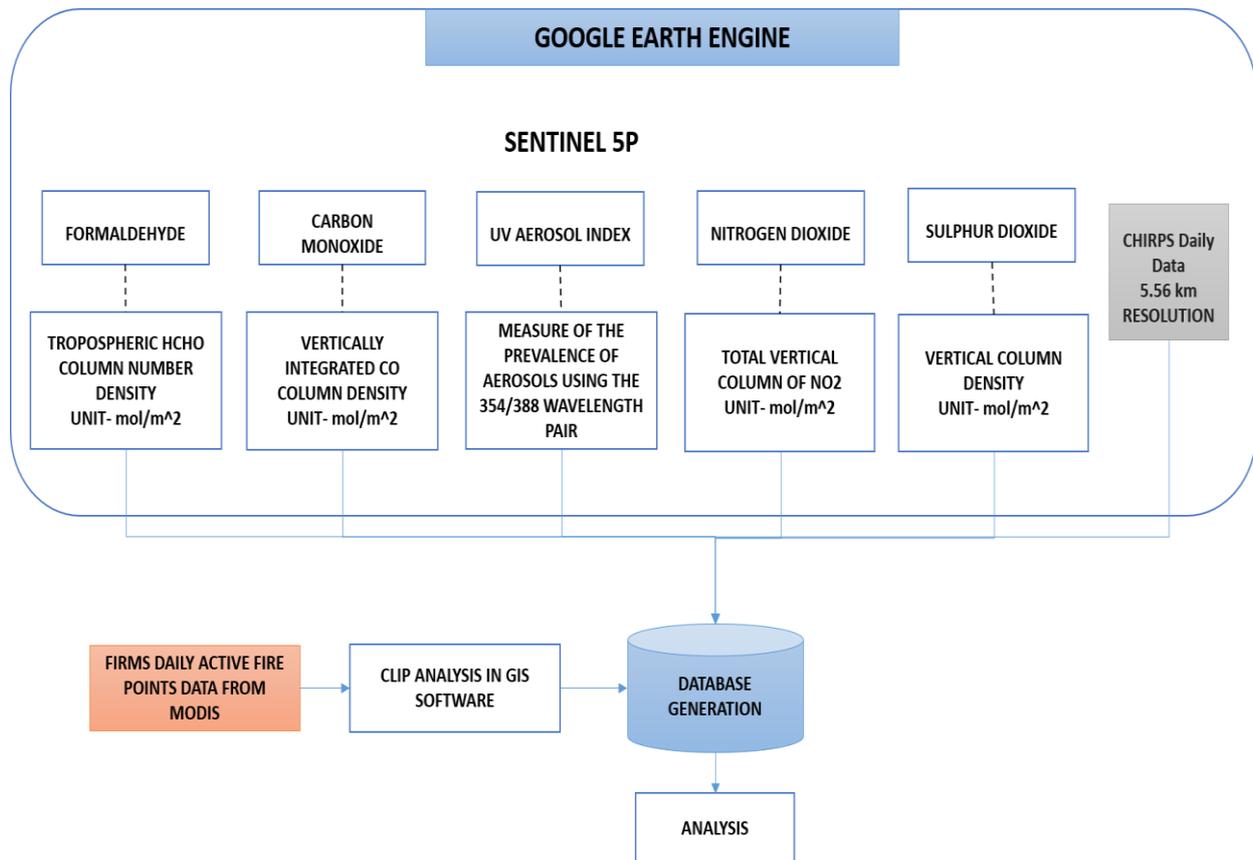


Figure 2. Methodology Flowchart

SL. NO.	NAME OF DATASET	TEMPORAL RESOLUTION	SPATIAL RESOLUTION	ACQUISITION PERIOD
1	SENTINEL 5P	DAILY	1.11 km	2019-2021
2	VIIRS-SNPP	DAILY	375 m	2019-2021
3	CHIRPS Daily	DAILY	5.56 km	2019-2021

Table 1. Details of datasets used

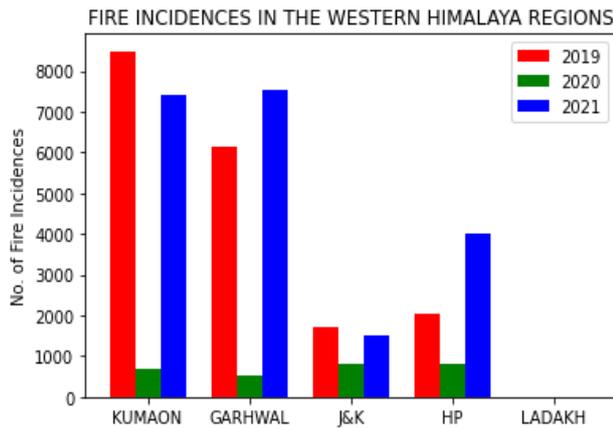


Figure 3. Number of fire incidences in the five regions of Western Himalaya

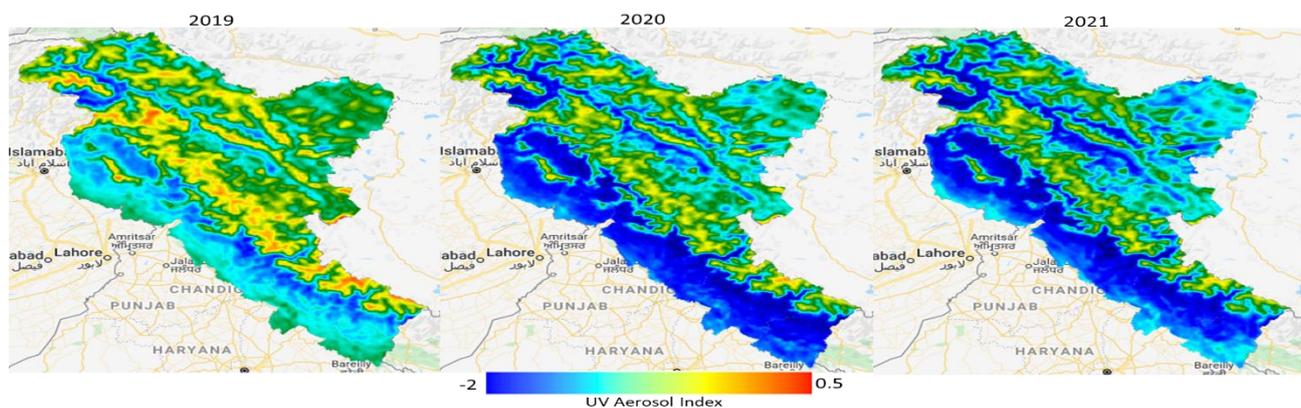
#### 4. RESULT

Highest concentration of  $\text{NO}_2$  is shown in the year 2021. Lowest concentration is observed in 2020. Maximum concentration is observed in some parts of Himachal Pradesh and Garhwal. Lowest tropospheric concentration is seen in Ladakh and the northern mountainous regions of Himachal Pradesh and Uttarakhand.

Highest concentration of CO is seen in the year 2021 then in 2019 and the lowest in 2020. In all these years maximum accumulation of tropospheric CO concentration is near the lower part of Kumaon region. Lowest concentration is seen in Ladakh. Tropospheric concentration is low in the mountainous regions of Himachal Pradesh and Uttarakhand.

Figure 4 indicates highest concentrations of aerosols in 2019 and the lowest in 2020. Positive UV AI are observed in the mountainous regions of Ladakh, Jammu and Kashmir. Negative UV AI are observed in the lower elevations of Jammu and Kashmir, Himachal Pradesh and Uttarakhand. Negative UV AI are highest in 2020 in the lower elevations of Jammu and Kashmir, Himachal Pradesh and Uttarakhand.

Higher concentrations of  $\text{SO}_2$  were found in scattered places. Due to lack of data the exact pattern of tropospheric  $\text{SO}_2$  concentration cannot be distinguished. Formaldehyde concentration was higher in the year 2021 in all the regions except Ladakh. The highest concentration of formaldehyde was found in the plain regions of Kumaon and Garhwal. The tropospheric concentration is lowest in Ladakh and the mountainous regions of Jammu and Kashmir, Himachal Pradesh and Uttarakhand. There is no concentration data for the year 2021 for Ladakh and northern mountainous regions of Himachal Pradesh and Uttarakhand. A considerable overall increase in fires events were observed in the study area. Number of fire events are highest in the year 2021 followed by 2019 then 2020. The year 2020 witnessed lowest fire incidences as a result of the COVID lockdown restrictions. In the year 2020, Ladakh witnessed 4 minor fire events that did not result in peak emissions. However, the later part of June saw high emissions of aerosols. The graph also shows that during the fire incidences less precipitation was recorded. In the year 2020, Kumaon saw significant fire events during February and mid-May which elevated the emission of aerosols. Precipitation lowered the emissions during March and June. In the year 2019, Himachal Pradesh saw great fire events from mid-May to June which elevated the emission of  $\text{NO}_2$ . Precipitation lowered the emissions during February. In the year 2021, Jammu and Kashmir saw significant fire events during April, May and June which elevated the emission of  $\text{NO}_2$ . Precipitation lowered the emissions during March and April. In the year 2019, Kumaon witnessed great fire events from April end to first week of June which raised the emission of CO. Precipitation dropped the emissions during March and April. In the year 2020, Himachal Pradesh witnessed great fire events during February and May which raised the emission of CO. Precipitation dropped the emissions from March to May. In the year 2020, Ladakh witnessed four minor fire events which did not impact the emission of  $\text{SO}_2$ . Precipitation dropped the emissions of  $\text{SO}_2$  during the fire season. In the year 2019, Garhwal saw significant fire events during May and June which did not impact the emission of  $\text{SO}_2$ . Precipitation dropped the emissions of  $\text{SO}_2$  during February, March and April. In the year 2021, Himachal Pradesh saw great fire events during March and April which elevated the emission of formaldehyde. Precipitation dropped the emissions of formaldehyde during April. In the year 2019, Garhwal saw significant fire events during May and June which elevated the emission of formaldehyde. Precipitation dropped the emissions of formaldehyde from February to April.



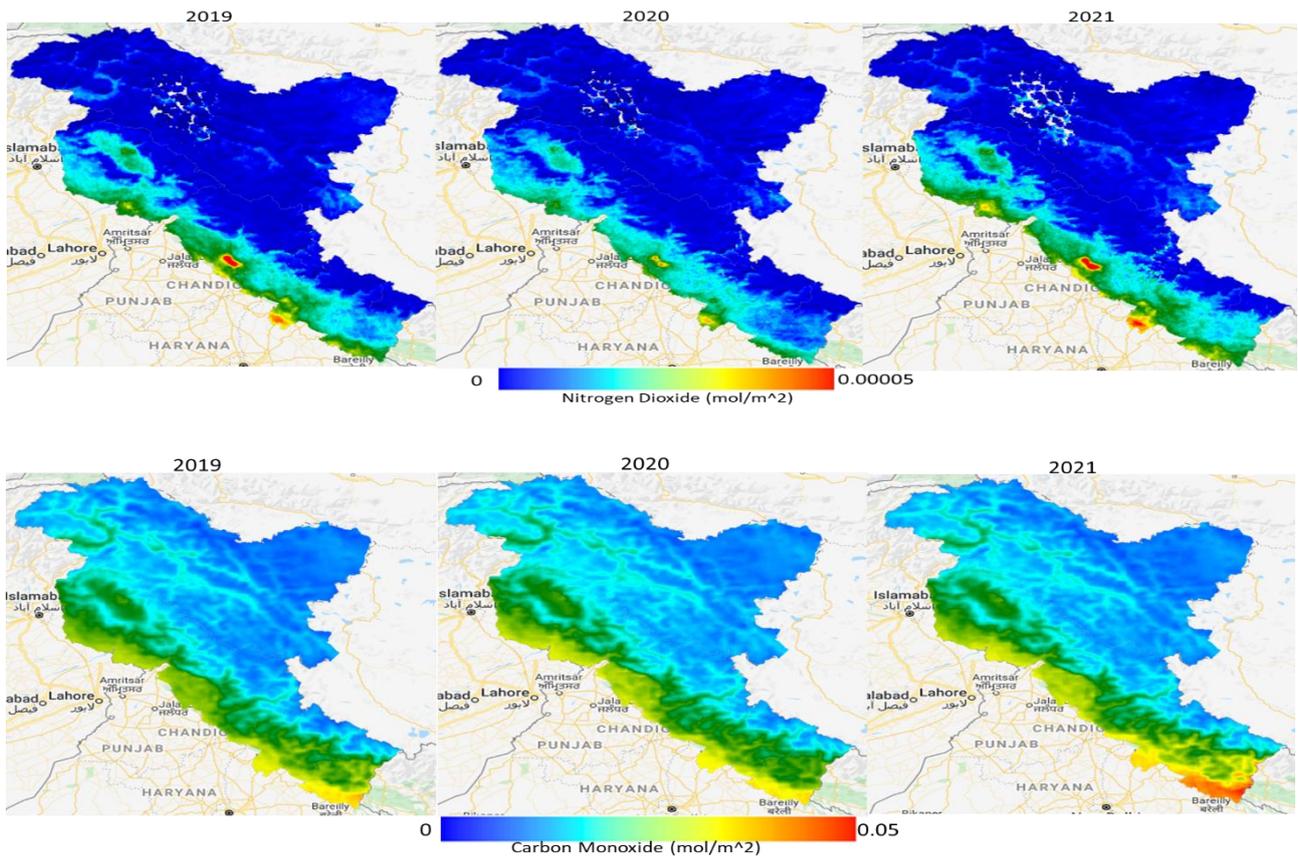
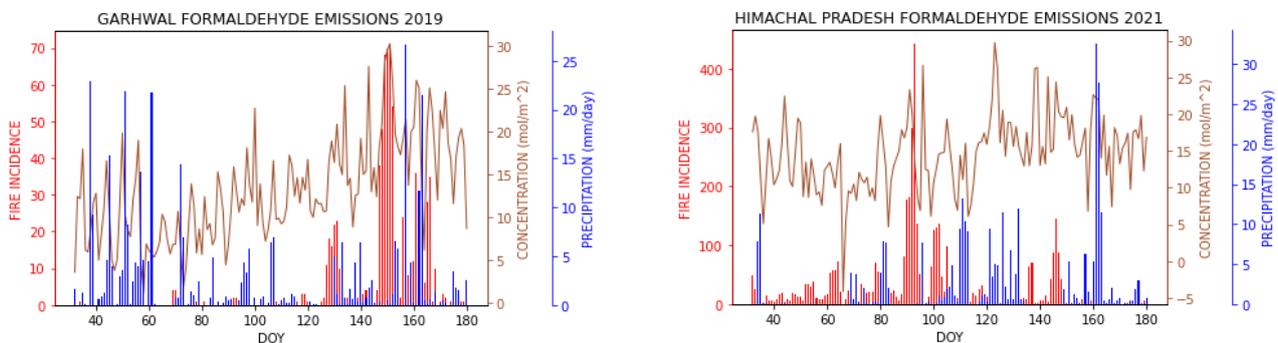


Figure 4. Concentration of NO<sub>2</sub>, CO and UV AI in the Western Himalaya.

Figure 5 shows graphs of some selected places and years depicting the daily fire, precipitation and emission data. Table 2 shows aerosols have weak to moderate positive correlation values for Kumaon, Garhwal and Himachal Pradesh. For Jammu and Kashmir aerosols showed weakly negative associations. For CO, there is moderately positive correlation for all the four regions. Similarly, NO<sub>2</sub> and HCHO have moderate to strong positive correlation for the four regions except few negative correlations.

The year 2020 gave low correlation values because of the less fire activity.

Correlation of the air quality parameters with the fire points was calculated and correlation coefficient ( $r$ ) was estimated for each parameter for every 5 regions. The  $r$  value describes the degree of association between two values. The value ranges from -1 to 1 showing negative and positive relations.



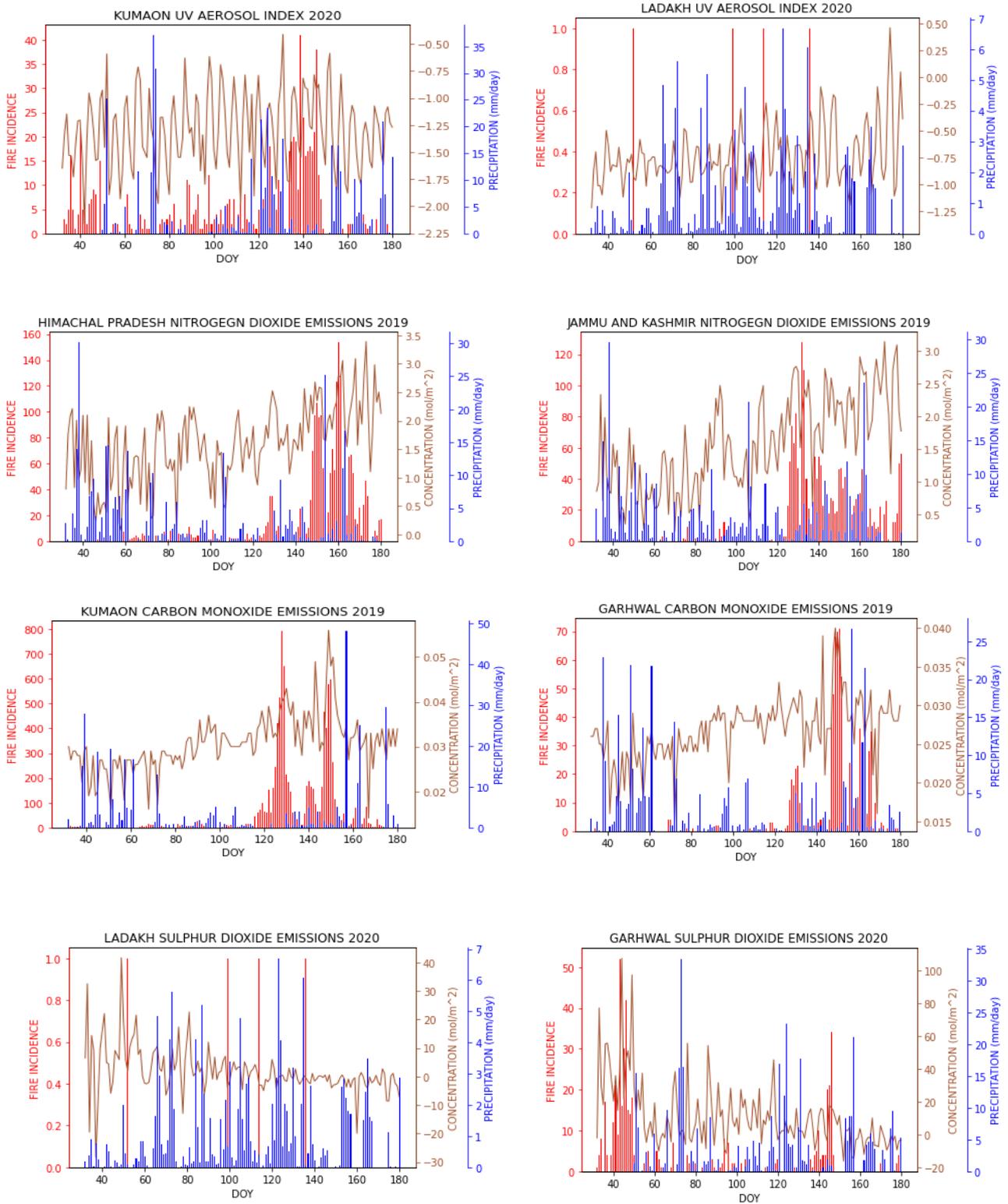


Figure 5: Graphs showing UV AI, concentration of Formaldehyde, Carbon Monoxide, Nitrogen Dioxide and Sulphur Dioxide with precipitation during the fire season of some selected places and year of the study area.

		HCHO	CO	AI	NO2	SO2
KUMAON	2019	0.5	0.6	0.5	0.5	0.0
	2020	0.2	0.2	0.2	0.2	0.2
	2021	0.2	0.3	0.4	0.3	0.1
GARHWAL	2019	0.6	0.5	0.3	0.5	-0.1
	2020	0.1	0.0	-0.1	0.2	0.4
	2021	0.2	0.3	0.3	0.2	0.0
HIMACHAL PRADESH	2019	0.5	0.3	0.2	0.5	-0.1
	2020	0.2	0.1	0.1	0.4	0.3
	2021	0.0	0.2	0.2	0.1	-0.1
JAMMU AND KASHMIR	2019	0.4	0.3	-0.1	0.5	-0.1
	2020	0.3	0.2	0.1	0.4	-0.2
	2021	0.3	0.3	-0.1	0.3	0.0

Table 2. Correlation values for all the gases with four region's fire incidences

## 5. CONCLUSION

This analysis presented the impact of the fire events on the tropospheric concentrations of these 5 major gases CO, NO<sub>2</sub>, HCHO, SO<sub>2</sub> and aerosol showed enhanced levels during fire events in almost all the five regions. Positive UV AI indicates the presence of UV-absorbing aerosols like dust and smoke. SO<sub>2</sub> shows weakly negative to weakly correlation with fire incidences which indicates there may be some external sources of SO<sub>2</sub> apart from the fire events for example emissions from vehicles and industries (Pierson et al., 1978). SO<sub>2</sub> from biomass burning is very small compared to the vehicular and industrial emissions. Tropospheric concentration of SO<sub>2</sub> climbed up during the tourism period, just before the lockdown started and during the easing of the lockdown restrictions. Precipitation helped to reduce the concentration of the gaseous pollutants. Not all the peaked emissions resulted from the biomass burning. The year 2020 saw lowest forest fire incidence as a result of the pandemic led lockdown which helped in improving the quality of air. Ladakh being a cold desert witnessed very small number of fire events which did not alter the tropospheric concentrations of these gas pollutants, region showed low to moderate correlation with all the five gaseous pollutants. Correlation coefficient of NO<sub>2</sub> is moderately correlated with the fire incidences. Formaldehyde presented moderated to high correlation for all the regions.

Many previous studies confirmed the increase of average temperatures, early onset of summer, less and erratic rainfall in the Western Himalaya (Bhutiyan et al., 2007; Dimri and Dash, 2012; Jain et al., 2009). Winter temperatures have warmed up faster in these mountainous regions than in the rest of the world. Forest fire season starts from February to June. Summer precipitation does little to reduce these forest fires. Vegetation type and tree species available in these regions like Chir pine are inflammable. Though they have adapted to forest fires because of their thick fire-resistant bark, the drier condition of these region makes the forest a tinder box (Bargali et al., 2020).

Western Himalaya is drier and vulnerable to climate change than Eastern Himalaya. Anthropogenic fire disturbances are damaging the forests ecology and the climate. Climate change leads to recurrent forest fire events releasing tonnes of carbon emissions (J S Bowman et al., 2013).

One major limitation of the study is that the data availability is only from 2018, so long term analysis of the impact of forest fire on air quality cannot be done with such high spatial and temporal resolution. With such high spatial and temporal resolution, this study of the air quality parameters can be further extended to broader interdisciplinary research relating to health, environment and social context which is crucial to build robust policies for climate change adaptation and protection of ecosystem services.

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