ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume V-3-2022
XXIV ISPRS Congress (2022 edition), 6–11 June 2022, Nice, France

ANALYZING SPATIO-TEMPORAL PATTERN OF THE FOREST FIRE BURNT AREA IN UTTARAKHAND USING SENTINEL- 2 DATA

Shailja Mamgain, Harish Karnatak*, Arijit Roy, Prakash Chauhan
shailja309@gmail.com, harish@iirs.gov.in, arijitroy@iirs.gov.in, prakash@iirs.gov.in

Indian Institute of Remote Sensing, ISRO, Dehradun, India

Commission III, ICWG III/IVa: Disaster Assessment, Monitoring and Management

KEY WORDS: Burnt area, Normalized Burn Ratio, Sentinel 2, correlation, multiple regression analysis, fire severity.

ABSTRACT:

Forest fire burnt area estimation using Normalized Burn Ratio at regional level helps in understanding the pattern of the frequency and severity of forest fires. In this study, burnt area is estimated for all the thirteen districts of Indian state Uttarakhand for last six years from 2016 to 2021 using Sentinel 2A and 2B datasets. The spatial and temporal pattern of the burnt area was analyzed by incorporating different parameters such as meteorological parameters like land surface temperature, rainfall; edaphic parameter like surface soil moisture and vegetation parameters like Normalized Difference Vegetation Index & Enhanced Vegetation Index. The estimated burnt area was statistically analyzed with respect to the parameters stated and the relationship among them was quantified. It was found that burnt area is positively correlated with the land surface temperature, while it showed negative correlation with the pre-fire precipitation, pre-fire NDVI & EVI and the surface soil moisture for 11 out of 13 districts. The district-wise forest fire burnt area assessment and analysis of its spatio-temporal pattern can be used in the preparedness and mitigation planning to prevent drastic ecological impacts of forest fires on the landscape.

1. INTRODUCTION

Forest fires affect more than 50 million hectares of area yearly around the world (Ryan, 2002; Stylianidis et al., 2020). It has great impact on the dynamics of the ecosystem structure and function. Estimation of the area burned due to forest fires helps in the assessment of the economic losses occurred as well as the damage caused to the flora and fauna in the area (Gupta et al., 2018). It also helps the forest managers to plan for the mitigation and restoration activities. Majority of the forest fires have anthropogenic causes which may be accidental or deliberate (Bahuguna & Singh, 2002). Deliberate fires can be ignited for many purposes such as collection of Sal seeds after fire, illegal timber extraction, scare away wild animals, improve grass growth, etc. (Bhandari et al., 2012).

Irrespective of the cause and purpose, forest fires damage to the forest ecosystem considerably depend upon its severity. Repeated burning in the forests result in destruction of the ground flora and reduced vegetative growth rate leading to change in the structure of the plant community and its soil nutrient status (Certini, 2005; Spanos et al., 2010). The fire season in Himalayan region marks its beginning from February and continue till June (Babu, 2019; ISFR, 2016, 2019; Satendra & Kaushik, 2014). The Himalayan region, particularly Uttarakhand, in addition to being a repository of natural resources, is also vulnerable to a plethora of natural and anthropogenically caused disasters (Karnatak & Roy, 2019).

Various studies have been carried out to identify and quantify the burned areas using satellite images but there is lack of studies focusing on its spatial and temporal pattern. Remote sensing is an effective tool in identifying and mapping the forest fire burnt areas since it can detect the changes in the fuel and soil moisture, chlorophyll content, removal of vegetation etc through the changes in the reflectance values (Jakubauskas et al., 1990). Gupta et al., (2018) classified the AWiFS (Advanced Wide Field Sensor) data from the RESOURCESAT-2 satellite for burnt area assessment using the hybrid (unsupervised and visual interpretation) classification algorithms for the fire episode of 2016 in Uttarakhand. Although the Normalized Burnt Ratio has been primarily used for locating and identifying the burnt areas and present the qualitative assessment of burn severity, however, many studies demonstrate a strong correlation between field-measured burned areas and NBR-derived burned areas (Roy et al., 2006; Wagtendonk et al., 2004). Two- band ratio approach is also being used due to its ability to discriminate the target feature based on the spectral differences (Twumasi et al., 2019).

The study has attempted to estimate the damage caused by the forest fires in all the thirteen districts of Uttarakhand in

* Corresponding author

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last six years from 2016 to 2021. The spatial and temporal pattern of burnt area was recognized for each district and its relation with different parameters like land surface temperature, precipitation, NDVI (Normalized Differenced Vegetation Index), EVI (Enhanced Vegetation Index) and surface soil moisture was analysed for each year. This study attempts to quantify the already stated relation of the burnt area with different weather and climatic parameters. The regional analysis of the burnt area pattern helps in understanding the forest fire frequency and severity pattern which can be used for enhancing forest fire control preparedness.

2. STUDY AREA

The study area for the present work comprises the total geographic area of Uttarakhand. It is a Himalayan state situated on the northern part of India. It has huge diversity in the flora and fauna. It covers the geographical area of 53,483 square kilometers, which is 1.63% of the total geographical area of the country. It has 45.44 % of total geographical area covered with forests out of which around 33% is moderately to extremely fire prone (ISFR, 2019). It has chir pine forests present in the mid to high elevation which primarily makes the region prone to forest fires. It experiences forest fires almost every year from February to June. The Uttarakhand state is administrated in two divisions, i.e. Kumaon and Garhwal comprising of thirteen districts: Almora, Bageshwar, Nainital, Champawat, Pithoragarh, Udham Singh Nagar in Kumaon region; Dehradun, Haridwar, Pauri, Tehri Garhwal, Uttarkashi, Chamoli and Rudraprayag in Garhwal region as shown in figure 1.

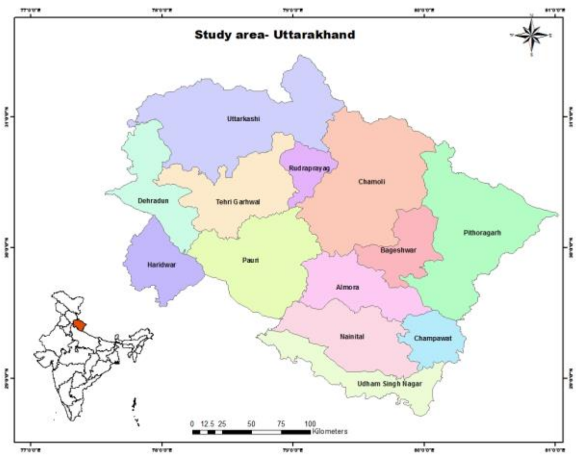

Figure 1. Study area map of Uttarakhand (India)

3. MATERIAL AND METHOD

3.1 Satellite dataset

In the present study, the optical datasets from Sentinel 2A and 2B Multi Spectral Instrument are used for the estimation of burnt area. These datasets were retrieved using a cloud computing platform of Google Earth Engine (GEE) for last six years i.e. from 2016 to 2021 for the Indian state of Uttarakhand. Datasets for different vegetation parameters, meteorological parameters and edaphic parameters were also retrieved for each district. These parameters included daily data of Land Surface Temperature, NDVI (Normalized Differenced Vegetation Index), EVI (Enhanced Vegetation Index), monthly data for precipitation and surface soil moisture. Data for precipitation, NDVI and EVI were taken for the pre fire season or the winter season i.e. for the month of December of previous year and January of the current year. Information of the datasets utilized in the study is given in Table 1.

3.2 Methodology

The satellite data from Sentinel 2 was used for the estimation of burned areas using an index called Normalized Burn Ratio (NBR) Index for all the thirteen districts of Uttarakhand. For this purpose, the satellite data was retrieved using GEE and masked for the forest areas. Then NBR was computed for the fire seasons for last 6 years i.e. from 2016 to 2021 using the formula shown below:

$$\text{pre} - \text{NBR} = \frac{NIR - SWIR}{NIR + SWIR}$$

$$\text{post} - \text{NBR} = \frac{NIR - SWIR}{NIR + SWIR}$$

Differenced NBR: dNBR = pre NBR – post NBR

Here, NIR and SWIR are the near infrared and short wave infrared bands respectively. NBR works on the technique of bi-temporal spectral difference where the burnt areas are identified by differencing the NBR of pre and post fire event. Value of dNBR ranges from -1 to +1 where negative values denote post- fire regrowth, zero shows unburned areas and positive values denote the burn severity of any area.

S. no.	Name of the dataset	Product ID	Spatial resolution	Temporal resolution	Time- period
1	Sentinel 2	--	30 m	5 days	2016-2021 (Feb-June)
2	EVI product	MOD13A2	1 Km	16- day composite	2016-2021 (Dec-Jan)

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3	NDVI product	MOD13A2	1 Km	16- day composite	2016-2021 (Dec-Jan)
4	Precipitation (mm/hour)	GPMV6	10 Km	Monthly	2016-2020 (Dec-Jan)
5	Land Surface Temperature (°C)	MYD11A1	1 Km	Daily	2016- 2021 (Feb-June)
6	Surface Soil Moisture (mm)	SMAP	10 Km	Monthly	2016-2021 (Feb-June)

Table 1. Details of the various satellite products used in the study

The datasets for different parameters such as temperature, precipitation, NDVI, EVI and moisture were retrieved using GEE for all the thirteen districts for last 6 years. Zonal statistics was performed using python programming language to get the burned area, mean temperature, mean NDVI, mean EVI, total precipitation and mean surface soil moisture for each district. The methodology flow chart for the study is shown in figure 2. The spatial and temporal pattern of the burnt areas for each district of Uttarakhand for last six years was analyzed and correlated with the five parameters mentioned to measure their degree of association. Multiple regression analysis was also done to determine the strength of the association between dependent and independent variables.

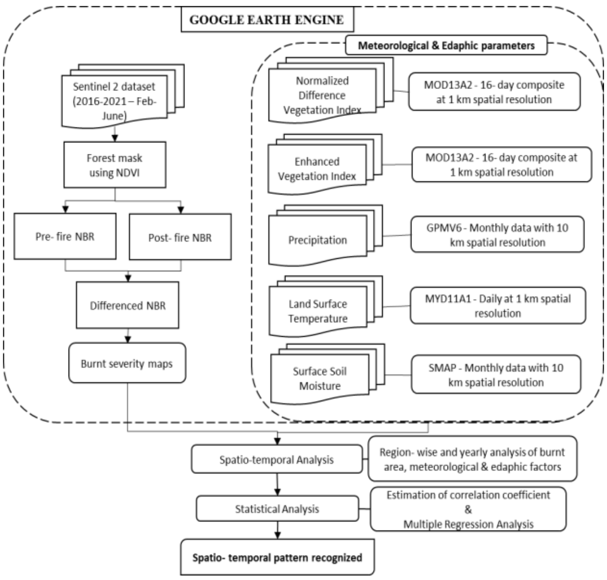

Figure 2. Methodology flow chart for the study

4. RESULTS AND DISCUSSION

Burnt area estimation using NBR for last six years in Uttarakhand state shows that considering the whole state, 2020 was the year with least burnt area while 2019 and 2021 were the years when the burnt area was estimated to be very high.

4.1 Spatio- temporal analysis

Spatio-temporal analysis of the burnt area for each district of Uttarakhand for last six years highlights that hill districts such as Chamoli, Pauri, Nainital, Pithoragarh and Tehri Garhwal were among the most fire-affected areas while Champawat, Rudraprayag, Almora and Bageshwar were least affected. Similar results were there in the study by Negi & Kumar, (2016) The overall burnt area for Udham Singh Nagar was recorded maximum but it might include the plantation areas also along with the natural forest. Since small fires are usually missed out for large regions, so estimation of burnt area at local or regional level is better than estimating it for broad areas (Gupta et al., 2018).

The spatio-temporal pattern of burnt area for all the districts could be better understood by considering the different parameters also such as land surface temperature, precipitation, NDVI, EVI and surface soil moisture. The figure 3 shows the pattern of burnt area in different districts in relation to the different parameters mentioned above.

In the figure 3, for Tehri Garhwal region, burnt area was estimated least in the year 2020, with mean land surface temperature also observing a dip in that year while pre fire precipitation, NDVI and EVI was high. Also the surface soil moisture was high during the fire season due to less fire severity. Similarly for the Uttarkashi region, burnt area was estimated less for 2017 even the temperature recorded was much higher. This was due to high pre-fire precipitation which helped in retaining the moisture in the soil during fire season and lowered the fire severity as shown in figure 3.

High forest fire severity was observed in the sub-tropical pine forests and tropical dry deciduous forests such as in Nainital in 2017 which could be due to the high temperature in the region during forest fire season and comparatively less pre-fire precipitation (Negi & Kumar, 2016). The areas in the proximity of the terai belt such as Pauri, Nainital and Haridwar experience high severity of forest fire (Sharma & Rikhari, 1997).

Also it has high abundance of the coniferous trees in its forest area which it flammable in nature (Girdhar, 2017). While for the year 2020, there was less severity owing to less temperature and high pre fire precipitation, NDVI and EVI conditions. Similar trend was seen for Almora district as well for the year 2020 as shown in the figure. General trend for nearly all the districts was followed as where there was a dip in the mean temperature for the fire season accompanied by the rise in pre fire precipitation, NDVI, EVI and the soil moisture, experienced less severity in that year and vice versa. District wise analysis helped in better understanding the spatial characteristics and the pattern of the burnt areas and the fire severity in the area.

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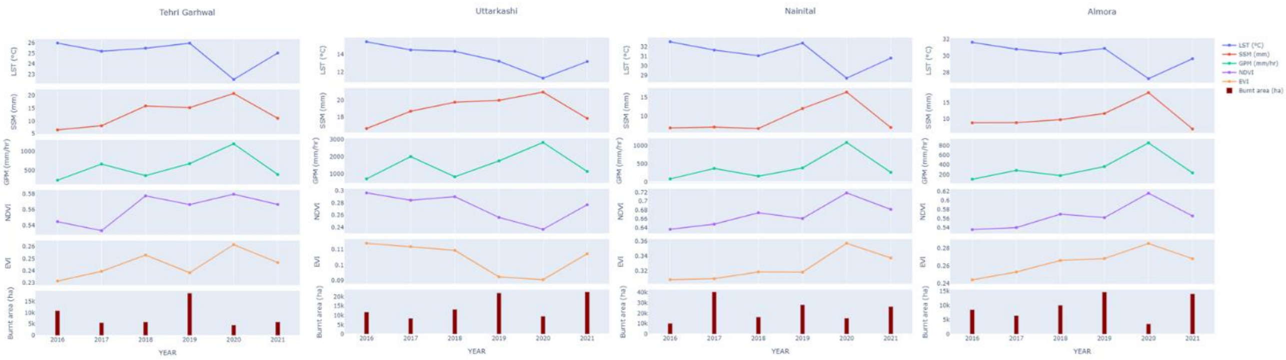

Figure 3. Spatio-temporal pattern of burnt area with the change in temperature, precipitation, NDVI, EVI and surface soil moisture

Study shows that the spatio-temporal pattern of the burnt area in last six years is affected by the abnormalities in the climatic parameters such as the erratic rainfall pattern i.e. heavy monsoonal rainfall but less winter precipitation/ drier winters, drought like conditions, decreasing trend in the diurnal temperature range etc (J. Sharma et al., 2017; Shekhar et al., 2010). Less precipitation in the winter season with warmer temperature reduces the amount of moisture retained in the soil, air and fuels during summers which leads to the increase in the severity and intensity of the forest fires during the fire season (Negi & Kumar, 2016).

4.2 Statistical analysis

Burnt area estimated using NBR was analyzed statistically with the different parameters mentioned above to quantify the correlation between burnt area and the various parameters. Correlation analysis showed that for around 9 out of 13 districts the pre fire precipitation, pre fire NDVI, pre fire EVI and the surface soil moisture showed the negative correlation with the burnt areas while land surface temperature showed the positive correlation with the burnt area. Table 2 shows the values of correlation coefficient for all the districts between burnt area and each parameter. Udham Singh Nagar district had a slightly different correlation, with NDVI and EVI being positively correlated with burnt areas. This could be due to the absence of natural forests in the district and abundance of plantation and agricultural lands (Negi & Kumar, 2016; Singh et al., 2016).

Similarly, for Pithoragarh district pre fire NDVI and EVI showed the positive correlation with the burnt areas which could be due to less precipitation in the pre fire season which led to high NDVI & EVI values in pre fire season and more fuel availability and thus high burn severity during the fire season (Fulé et al., 2021). For Almora district, LST showed weak positive association with the burnt area and NDVI & EVI showed weak negative association while pre fire precipitation and the surface soil moisture during the fire season showed strong negative association with the burn severity in the area.

Multiple regression analysis was done taking burnt area as the dependent variable and other parameters as the independent variables. Regression analysis is a tool for determining the relationship between two or more variables. The value for coefficient of determination i.e. R- square value ranged from 0.66 to 0.89 for all the districts of Uttarakhand implying that the regression model was very well able to account for the variance in the independent variables.

District	LST (°C)	GPM (mm/hr)	NDVI	EVI	SSM (mm)
Almora	0.47	-0.53	-0.34	-0.11	-0.58
Bageshwar	0.02	0.03	-0.20	0.39	0.20
Chamoli	-0.22	-0.22	0.05	0.12	0.03
Champawat	0.27	-0.31	-0.45	-0.36	-0.47
Dehradun	0.58	-0.53	-0.08	-0.41	-0.09
Haridwar	0.66	-0.53	-0.25	-0.16	0.02
Nainital	0.21	-0.04	-0.23	-0.25	-0.18
Pauri	0.47	-0.43	-0.45	-0.23	-0.58
Pithoragarh	0.38	-0.66	0.42	0.45	-0.31
Rudraprayag	0.27	-0.53	0.33	0.14	-0.02
Tehri Garhwal	0.57	-0.16	-0.07	-0.59	-0.08
Udham Singh Nagar	0.02	-0.44	0.18	0.43	0.14
Uttarkashi	-0.14	-0.30	-0.10	-0.24	-0.09
Mean correlation for Uttarakhand	**0.27**	**-0.36**	**-0.09**	**-0.06**	**-0.15**

Table 2. Correlation coefficient values for all the districts and mean for Uttarakhand

District	R- square
Almora	0.87
Bageshwar	0.84
Chamoli	0.78
Champawat	0.66
Dehradun	0.88
Haridwar	0.88
Nainital	0.80
Pauri	0.83
Pithoragarh	0.81
Rudraprayag	0.88
Tehri Garhwal	0.89
Udham Singh Nagar	0.89
Uttarkashi	0.89
Mean for Uttarakhand	**0.84**

Table 3. Coefficient of determination (R- square) values for burnt area with all the parameters for each district and mean for Uttarakhand

The R- square value for Tehri Garhwal, Udham Singh Nagar and Uttarkashi was approximately 0.89 which states that all the independent factors were able to account for the dependent factor i.e. the burnt area while for Champawat, the r- square value was the lowest i.e. 0.66 which implies that more independent variables such as relative humidity, fuel moisture content, dew point temperature etc. are needed to account for the variance in the pattern of burnt area in this region.

5. CONCLUSION

This study concludes that the analysis of the spatial and temporal pattern at local or regional level is more advantageous that doing it for large area, since it accounts for the local variations in the conditions of temperature, precipitation, moisture and vegetation conditions. Analysis of the long term pattern of the burn severity can be done most effectively using geospatial technology. This information can help the forest officials, administrative authorities, and the parliamentary committee for a long term recovery plan for tackling the situation of forest fires in future.

ACKNOWLEDGEMENTS

We express our sincere thanks to the anonymous reviewers for their invaluable comments. Their contribution improved the quality of the manuscript.

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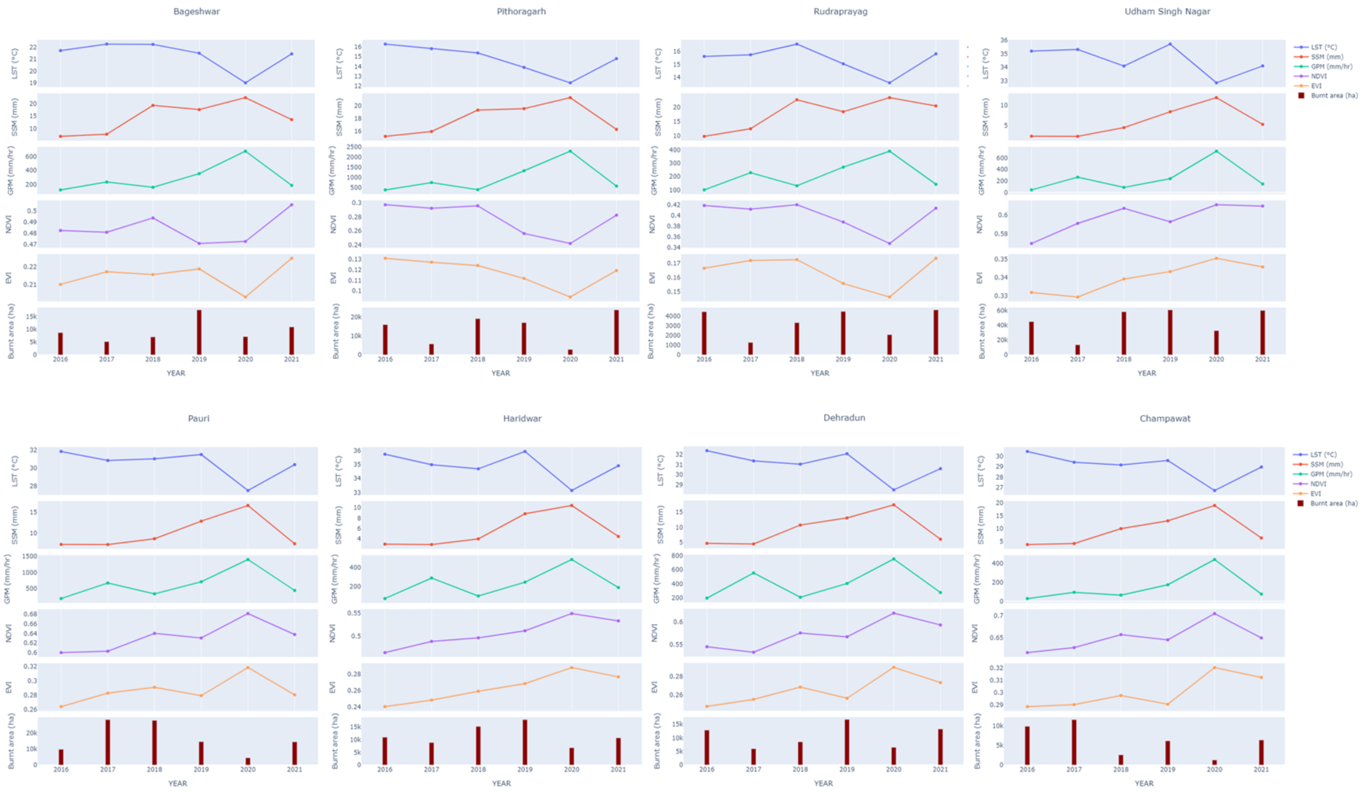
APPENDIX

The spatio-temporal pattern of burnt area with the change in temperature, precipitation, NDVI, EVI and surface soil moisture for all the districts (except those in Figure 3) is shown in the following figure.



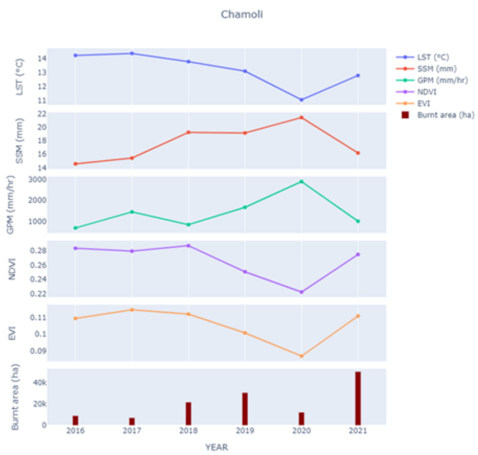


Figure 4. Spatio-temporal pattern of burnt area with the change in temperature, precipitation, NDVI, EVI and surface soil moisture for remaining nine districts of Uttarakhand