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Forest Fire Severity Mapping Of Humid Tropical Regions: A Geospatial Perspective

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Abstract: Forest fire is important ecological stress caused by climate change and related global warming. The frequency and severity of forest fires are anticipated to have a significant impact on the characteristics of tropical forests. The forest areas in Uttarakhand are often affected by fires results ina high ecological loss. Identification of forest fire hotspot areas and related management is a prerequisite of forest fire management. The objective of this study is to map the burn severity in the summer times of 2016 and 2017 for the Almora and Bageshwar districts of the Chamoli division in Uttarakhand. Remote Sensing Indices such as Normalized Difference Vegetation Index (NDVI) and Normalized Burn Ratio (NBR) are used for burn severity classification and vegetation analysis respectively. The result showed that, compared to pre-fire NDVI, the average NDVI Value of Post-Time Fire was lowwhich indicates a change in vegetation cover especially in moderate to high burned areas. The result also indicates a weak inverse relationship between NDVI and LST, but it was moderate weak to moderate, overall in the study area. The study concludes overall moderate to strong correlation, between LST and NBR in both pre-fire and post-fire NBR

Keywords: NDVI, NBR, LST, Burn Severity, Landsat, Pre-Fire, Post-Fire.

1. INTRODUCTION

Forest fire is a worldwide problem nowadays (Stephens and Ruth 2005). It harmsecosystem structure, biogeochemical cycling, and atmospheric chemistry. The forest fire parameters identification and mapping of the severity level are the important prerequisites for the forest fire management process. The study tries to understand the land surface temperature (LST) after using the LANDSAT image. The indices derived from LANDSAT bands are used to understand the level of vulnerability in the ecosystem (Verma and Jayakumar 2012).

In the previous studies,TeodoroandAmeral(2019) found that photosynthesis activity and NDVI values decreased considerably in forest fire events. *S. Esceunetal* assessed fire severity in two ways. Separating the unburned pixels from the rest based on their dNBR value, and separating the extreme severity pixels from the moderate severity are based on their NBR post value.

Philippetal. (2019) used optical satellite imagery for estimating burn vulnerability and fire scars in tropical surana. To understand the vegetation's response to fire, they used SAR data. The study also compared pre and post-fire results of Sentinel-1C-based backscatter intensity data to those of optical satellite imagery.It found that Sentinel-1C-based backscatter successfully sensed fire-induced structural changes.Nicholas et al. (2010)used Landsat derived differential Normalized Burn Ration (dNBR) algorithm to predict burn severity in western Canada and later on, they compared it to its relative form (RdNBR). Theyconcluded that RdNBR would be a better estimator of burn severity.

Chafer et al (2003)try to understand the fire vulnerability of the 2001 Sydney basin wildfire of Australia.They compared the NDVI values of pre and post-fire times. They gave a differential range (NDVIdiff) and categorized the whole area into six different severity classes.Later on, they tested validated after verifying the result into 342 small areas within the whole basin (e.g 22500 hectors fire-affected area). Based on this existing research, Remote Sensing indices have been extensively used for the present study.

India also facing adverse forest fires in different parts of the country (Joseph et al. 2009). Over 40 percent of Uttarakhand's forests are susceptible to fire. According to a forest survey of India report, more than 36 percent of Indian forest cover is impacted by forest fire, out of this 10 percent are highly susceptible to the adverse forest fire.

The Uttarakhand which is among the most fire-affected area of India needs accurate mapping of damaged areas. The summer times of 2016 and 2017 in Uttrakhand seen a devastating forest fire with high ecological loss. Therefore it needs an hour to map the fire-damaged areas and the areas that need immediate attention in perspectives of forest fire management. The present study is an attempt to understand the adverse impact of forest fire on the ecological system. The study also tries to attempt to formulate the fire management in Almora and Bageshwar districts of Chamoli division in Uttrakhand.

Objectives

The objectives for the present study are-

(i) To map burn severity using dNBR according to USGS Classification

(ii) To observe the change in vegetation cover using NDVI &dNDVI

(iii) To observe the correlation between LST, dNDVI, and Burn Severity to find relationship between temperature and vegetation change and/or burn severity.

Study Area

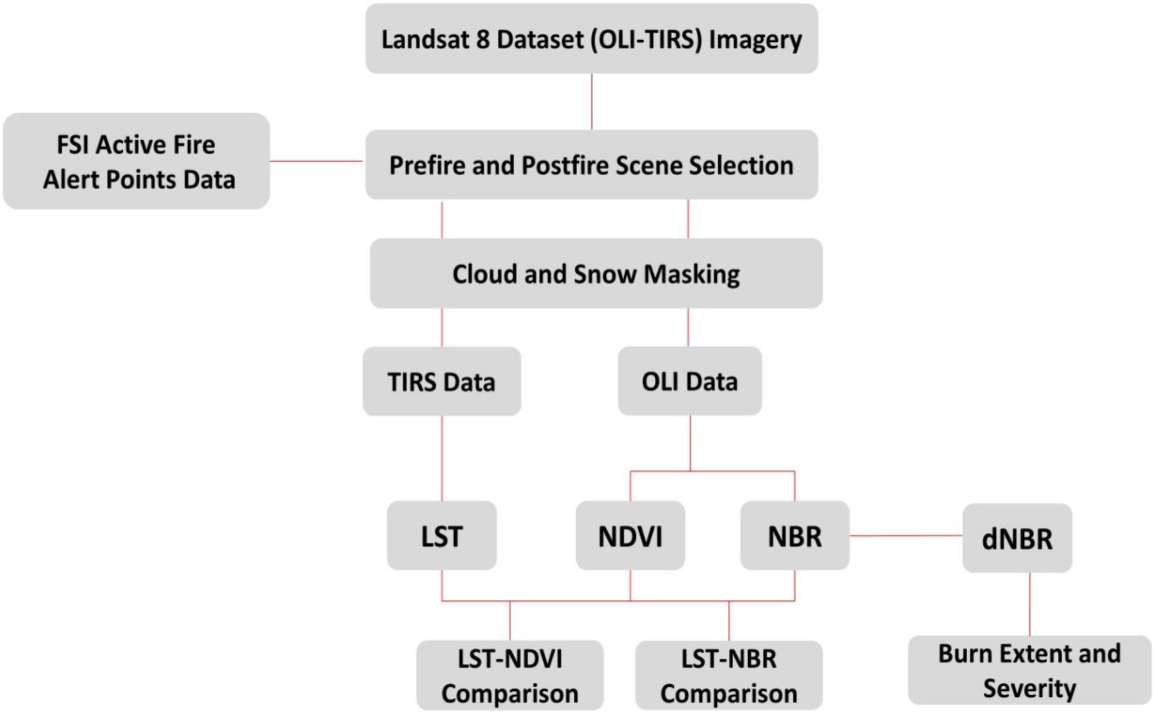
The study area comprised of 2 Districts (Level-2 Administrative division) viz. Almora and Bageshwarare located in Uttarakhand (India). Almora district covers an area of 3101 sq. km. and Bageshwar covers 2280 Sq. km.The study area extent fell between latitudes 29° 25' 55.67" - 30° 19' 14.84" N and longitudes 79° 1' 26.79" - 80° 8' 49.1"E. The study area has Subtropical Pine forests and some Alpine forests (Champion and Seth1968). The area receives >1000 mm of precipitation annually including rainfall and snow in northern parts and has cooler climatic conditions and it is distributed in Himalayan terrain (Rawat and Kumar 2015). The Almora district receives 878.64 mm of rainfall annually on average and in the monsoon season only (June to September) it receives 624.78 mm of average rainfall (Joshi et al. 2013). Whereas, Bageshwar district receives 1253.94 mm of average annual rainfall, and specifically in monsoon season it receives 1021.17 mm of average rainfall (Malik et al. 2019). In addition, the average monthly temperatures in this area range from as low as 15 degrees Celsius to 2 degrees Celsius in winter and as much as high from 17.2 °C to 30.0 °C in summer. The vegetation includestree species such as *Pinusroxburghii*(Longleaf Indian Pine), *Quercussemecarpifolia*(Brown Oak), *Quercusfloribunda*(Green Oak), *Cedrusdeodara* (Himalayan Cedar), etc.which are common foundin the area (Arya and Tamta 2016).

'Figure 1. Study area map showing the location of the two districts i.e. Almora and Bageshwar.' is to be included here

2. METHODOLOGY

Datasets and Preprocessing

Prefire and Postfire satellite imagery was acquired for the analysis dated May 7, 2019 (Prefire) and May 23, 2019 (Postfire).Landsat-8 satellite images were used in this studywhich included the use of Bands No. 4 (Red), 5 (Near-Infrared, NIR), 7 (Shortwave Infrared – 2, SWIR-2), and 10 (Thermal Infrared, TIRS 1). The imagery encompassing the two districts fall in LANDSAT WRS (World Reference System) Path 145 and Row 39. The Landsat-8 Bands 4, 5, and 7 had a pixel resolution of 30m whereas the Band 10 (TIRS-1) had a pixel resolution of 100m. Level-1 Landsat data was used for obtaining LST and NDVI whereas Level-2 was used for making NBR (Normalized Burn Ratio). The datasets were obtained from USGS Earth Explorer online platform. The images are cropped according to the study area (Fig 1.) with WGS 84 Coordinate Reference System and projected in UTM (Universal Transverse Mercator) Zone 44N in QGIS Open Source Environment.



Detection of fires

The active fire information was obtained from the UttarakhandState's Forest Department website which keeps track of fires month-wise on multiple days in a month in the form of point data shown on maps for a particular day based on the primary data provided by the Forest Survey of India. As for the selection of the prefire imagery, it is important to get preliminary information of fire detection especially the date and the extent of the fire and therefore we selected the Prefire date as May 7, 2019,because most of the active fires were only present for first time in the month on May 8, 2019, in the study area whereas the Postfire data was selected on May 23, 2019, keeping in mind the availability of satellite imagery and to avoid advent of monsoon season (Uttarakhand Forest Department 2019).

Cloud & Snow Masking

The Landsat-8 Level-2 product contains a Pixel Quality Assurance (pixel_qa) Band which contains information such as Clouds, Cirrus, Snow, Water, etc. As this single Band contains multiple classes containing information, Landsat QA ArcGIS Toolbox was used for unpacking the useful classes (cloud and snow only) to achieve cloud and snow masking as it covered significant portions of the study area. Other masks were not applied as it occupied a very negligible portion of the study area. After the masks were applied remaining total area observable for our Burn Severity assessment was 4596 Sq. km.

Remote Sensing Indices

Remote sensing indices were used in this analysis for burn severity classification as well as vegetation analysis. The vegetation index and burn index included NDVI and NBR respectively.Landsat-8 NDVI is computed as shown in Eq. 1.

$$NDVI = \frac{Band5-Band4}{Band5+Band4} \quad \text{Equation 1}$$

NDVI values fall between a range of -1 to +1. Positive values are representative of green vegetation whereas Negative values indicate the absence of vegetation usually includes water and snow. Values close to 0 usually represent land without the presence of vegetation (Carlson and Ripley 1997).For snow-covered areas, NDVI tends to have negative values (Huemmrich et al. 1999).

For measuring burn severity, firstly Landsat-8 NBR was measured for both Prefire and Postfire images as shown in Eq. 2.

$$NBR = \frac{Band5-Band7}{Band5+Band7} \quad \text{Equation 2}$$

Secondly, once NBR has obtained the difference between the Prefire NBR and PostfireNBR prepared i.e. dNBR (Difference Normalized Burn Ratio) is obtained which provides the estimation of the burned area extent and severity. This requires the dNBR values to classify according to different levels of burn severity initially proposed by USGS as shown in

Table.1.

"Table 1. Burn Severity Categories and their respective dNBR value limits " is to be inserted here

Land Surface Temperatures

The LSTs were retrieved by using Band 10 and NDVI as inputsafter using QGIS. Firstly, Top-of-Atmosphere (TOA) radiance is obtained by converting DN (Digital Numbers) i.e. raw data of Landsat-8 Level 1 Product Images per pixel by using the radiance scaling factors provided in the metadata. Secondly, TOA radiance is converted to At-Satellite Brightness Temperature (also known as blackbody temperature) assuming uniform emissivity using metadata information on pre-launch calibration constants. Lastly,Emissivity is calculated using the scaled NDVI method based on the Vegetation cover (Valor and Caselles 1996) followed by the LST calculation shown in Eq. 3.

$$S_t = \frac{T_B}{1+\left(\frac{\lambda \times T_B}{\rho}\right) ln\varepsilon} \quad (3)$$

Where, T_B= at-satellite brightness temperature, λ = wavelength of the emitted radiance, whereas in ρ = h×c/σ, h = Planck's constant (6.626×10^{-34} Js), c = velocity of (2.998×10^{8} m/s) and σ= Boltzmann constant 1.38×10^{-23} J/K(Weng et al. 2004).

3. RESULT AND DISCUSSION

The NDVI Map of the Prefire scene shows clearly the presence of moderate to high values of NDVI which would suggest most of the vegetation was undisturbed before the forest fires that occurred mostly after May 7. The average NDVI value was 0.41 for the prefire scene. Nevertheless, in the northernmost part of the Bageshwar district, most of the areas were covered by snow and cloud. So the informationis considered lost. However, small patches of snow which reflect negative NDVI are visible (Fig 2).

"Figure 2. NDVI Map of Prefire scene of the study area " is to be inserted here

Compared to Prefire NDVI, the average NDVI value of postfire time was low i.e. 0.29 for the Postfire scene which suggests a change in vegetation cover especially in moderate to the high burned area (Fig. 3). The central part of the study witnessedthe lowest NDVI values in the Postfire scene which is a clear change from Prefire scene. In addition, the Postfire scene has more clouds and even the clouds are present in Almora and Southern Bageshwar. This also shows the advent of monsoon as most of the available images (after May) that were observed on other satellite images were fully covered with cloud.

"Figure 3. NDVI Map of Postfire scene of the study area" is to be inserted here

The average LST value for the study area was 29.35 °C for the prefire scene (Fig. 4). Especially in the areas of higher intensity of burn (Fig. 6). It can be compared that the LST was relatively higher. Hence, most of the higher LST values were present in Almora. Due to snow cover, the temperatures seem very low which is almost similar to the Postfire LST scene in the northern parts of Bageshwar(Fig. 5).

"*Figure 4. LST Map of Prefire scene of the study area" is to be inserted here*

The average LST value was 24.2 °C for the postfire scene (Fig 5). Thus, LSTs were lower than Prefire scene, and only relatively high LSTs were observed in the burned areas as observed in other studies where burned zone are found to be significantly warmer (upto 7.6 °C warmer) than unburned and high severity zones can be above 10 °C warmer than unburned zones (Vlassova et al. 2014).

"Figure5. LST Map of Postfire scene of the study area" is to be inserted here

As per Fig. 6 Enhanced regrowth has been observed in areas close to snow cover (>2% of the area) which is also visible in the Postfire NDVI map (Fig 3). The major reason behind this could be the snowmelt because NDVI values drop due to snowfall but as soon as the snow melts it has seen that NDVI spikes in those areas (Huemmrich et al. 1999). Nevertheless, most of the study area has remained unburned (>80%) followed by the low severity which was 16.88% (Table 2). If we consider the top three categories of severity viz. Moderate-Low, Moderate-High, and High as burnt areas with higher confidence than 3349 Hectares (~0.7%) are burnt with high confidence but from Low to High Severity (all 4 classes of the broader burned category) i.e. 80,910 hectares (~17.5%) can be still considered as burned area(Table 2).

"Figure6. dNBR based Burn Severity Map of Postfire scene of the study area." Is to be inserted here

"Table 2. Category-wise Area (in hectares) and Percent Burn Severity" is to be inserted here

As per Fig 6 and Table 2, it is evident that most of the central part of the study area witnessed moderate to high severity burns.

"Figure 7. Correlation Matrix for NDVI-LST Relation" is to be inserted here

In addition, the NDVI-LST relation shows a weak inverse relationship (r = -0.155) (Fig. 7). As observed in the maps also it is observed that Postfire NDVI is right-skewed meaning lower NDVI values are more than higher values of NDVI in contrast to Prefire values which show normal distribution. Furthermore, the LST values show left-skewness i.e. more observation of higher temperatures. However, individually Postfire and Prefire correlation was moderate to strong respectively. In similar climates i.e. Humid Subtropical Climate (Cfa), studies have shown LST-NDVI to havea strong negative correlation, which is significantly corresponding to our results (Guha et al. 2018).

"Figure 8. Correlation Matrix for NBR-LST Relation" is to be inserted here

There is an inverse correlation between NBR and LST just as with NDVI but greater in magnitude (r = -0.52). The skewness property of NBR-LST is almost similar as NDVI-LST because both NBR and NDVI indices are similar from a perspective of vegetation although dNBR is interpreted differently. Although, for Prefire NBR negative but strong correlation has been observed with LST and Postfire moderate to strong correlation is found.

4. CONCLUSION

Forest fire is an emerging issue for environmental scientists. The LULC change and related conversion of preoccupied forest land to agricultural land make it more vulnerable. Global warming and unscientific anthropogenic activity make it more vulnerable in humid and sub-humid deciduous forest areas. The present study tries to attempt the forest fire severity of a humid forest area namely in the Uttrakhand district of India. This study provided burn severity and extent mapping using satellite imagery. Ithas eliminated the false estimation of NBR and NDVI after proper treatment of Cloud and Snow cover pixels thus providing high accuracy in burn severity estimation. The use of State department and FSI point data for active fires can be important in preliminary information required before this sort of analysis. The study found NDVI-LST had an inverse relationship but it was moderate weak to moderate overall in the study area which is categorized by Humid Subtropical Climate (Cfa) and this inverse relationship has been found in the previous study although this relationship is subject to seasonal variation. However, it is recommended that more research on the understanding seasonal LST-NDVI or LST-NBR relation can be done when understanding long-term monitoring of forest fires. Lastly, the study concludes that as there was an overall moderate to strong correlation found between LST and NBR (both Prefire and Postfire NBR), this suggests monitoring LSTs is highly necessary for future forest fire monitoring.

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Tables

Table 1. Burn Severity Categories and their respective dNBR value limits

dNBR values limits	Burn Severity Category
-0.500 to -0.251	High, Enhanced Regrowth
-0.250 to -0.101	Low, Enhanced Regrowth
-0.100 to +0.099	Unburnt

+0.100 to +0.269	Burn, Low
+0.270 to +0.439	Burn, Moderate to low
+0.440 to +0.659	Burn, Moderate to high
+0.660 to +1.300	Burn, High

Source (Mutai and Chang 2020)

Table 2. Category-wise Area (in hectares) and Percent Burn Severity

Categories	Area (in hectares)	% Area
High, Enhanced Regrowth	765	0.17
Low, Enhanced Regrowth	9,639	2.10
Unburnt	368,285	80.13
Burn, Low	77,561	16.88
Burn, Moderate to low	3,015	0.66
Burn, Moderate to high	202	0.04
Burn, High	132	0.03
Total	459,599	100

Figures

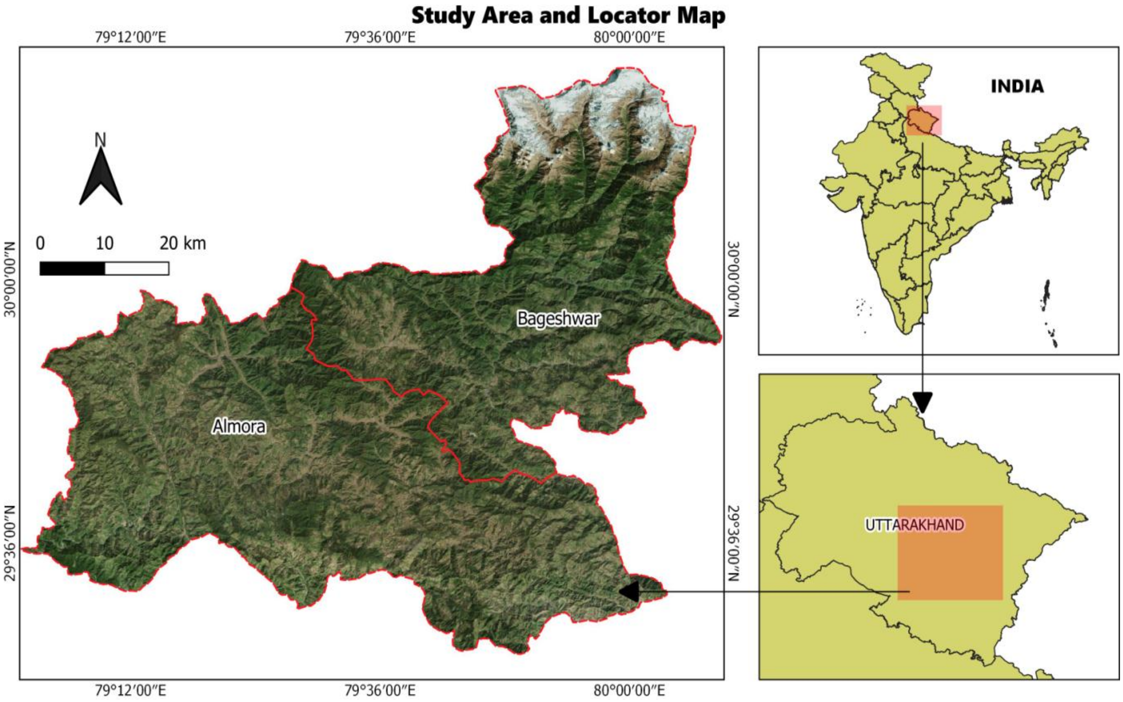


Figure 1. Study area map showing the location of the two districts i.e. Almora and Bageshwar

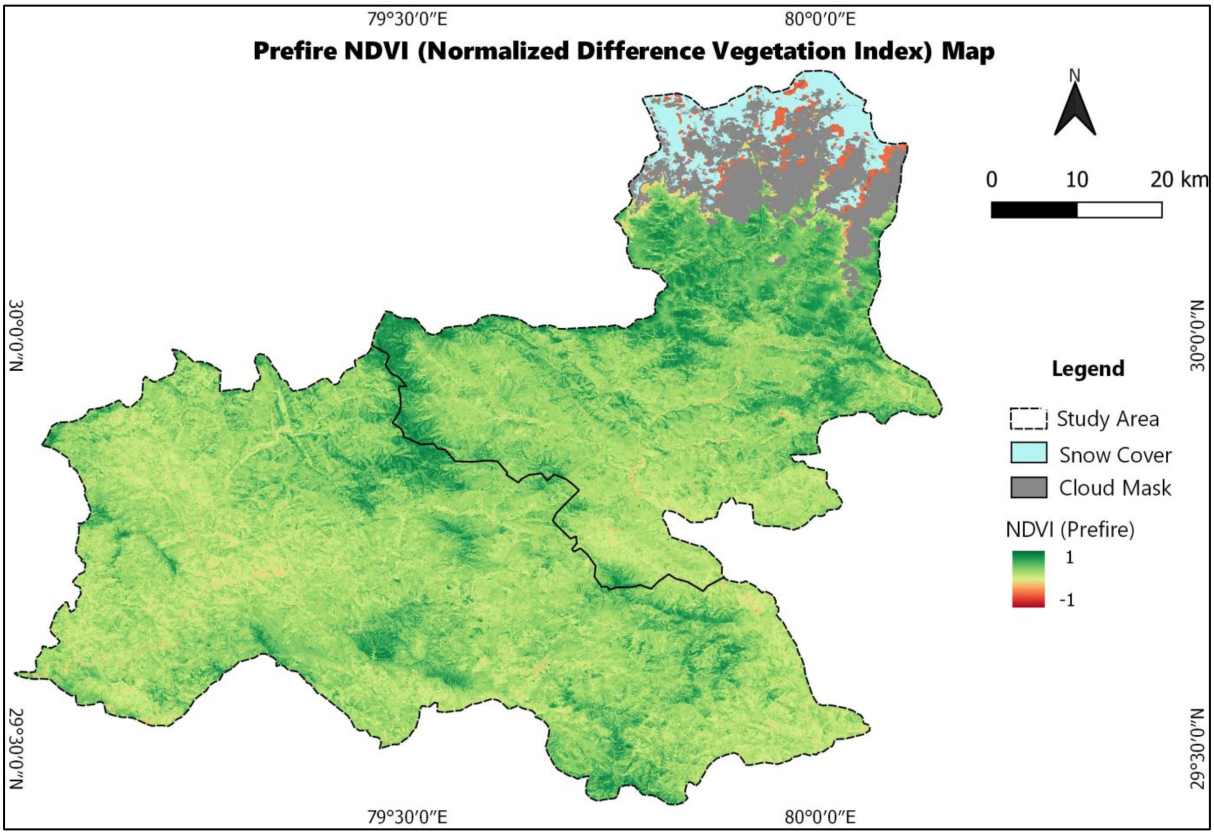


Figure 2. NDVI Map of Prefire scene of the study area

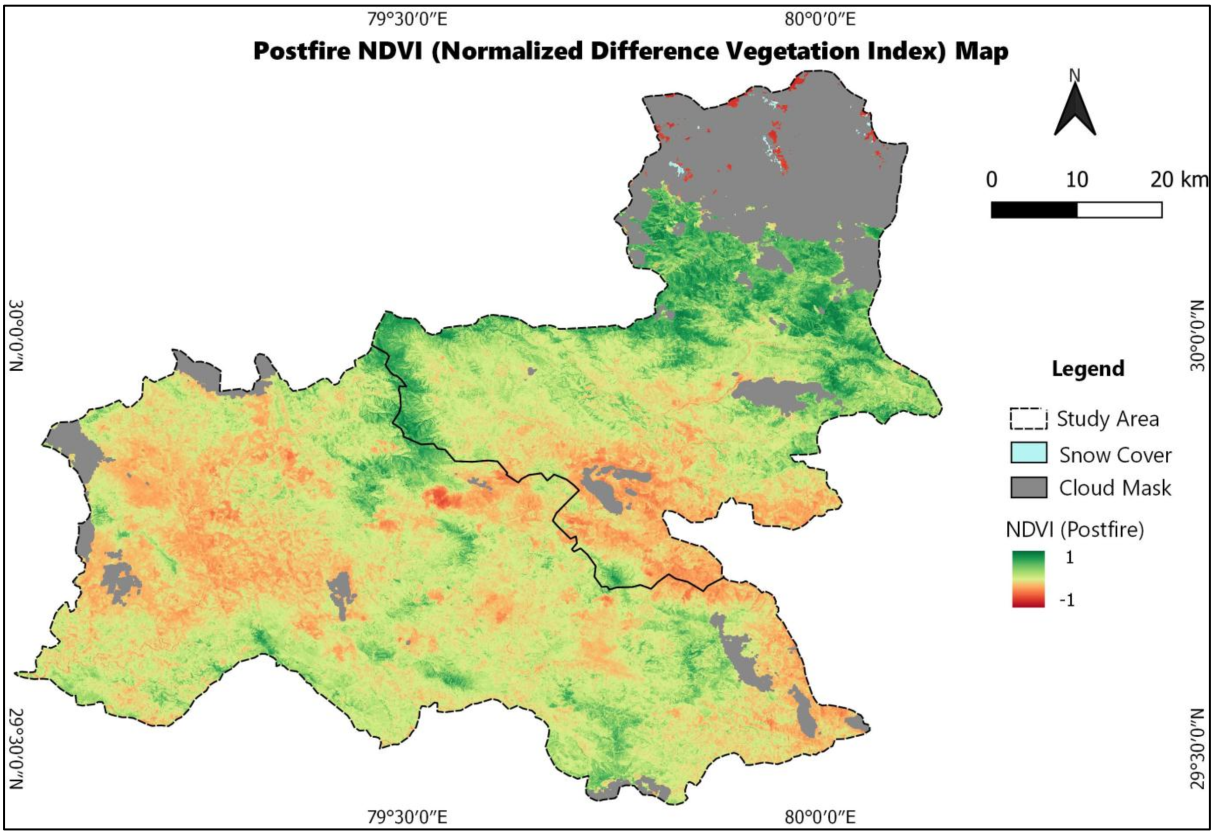


Figure 3. NDVI Map of Postfire scene of the study area

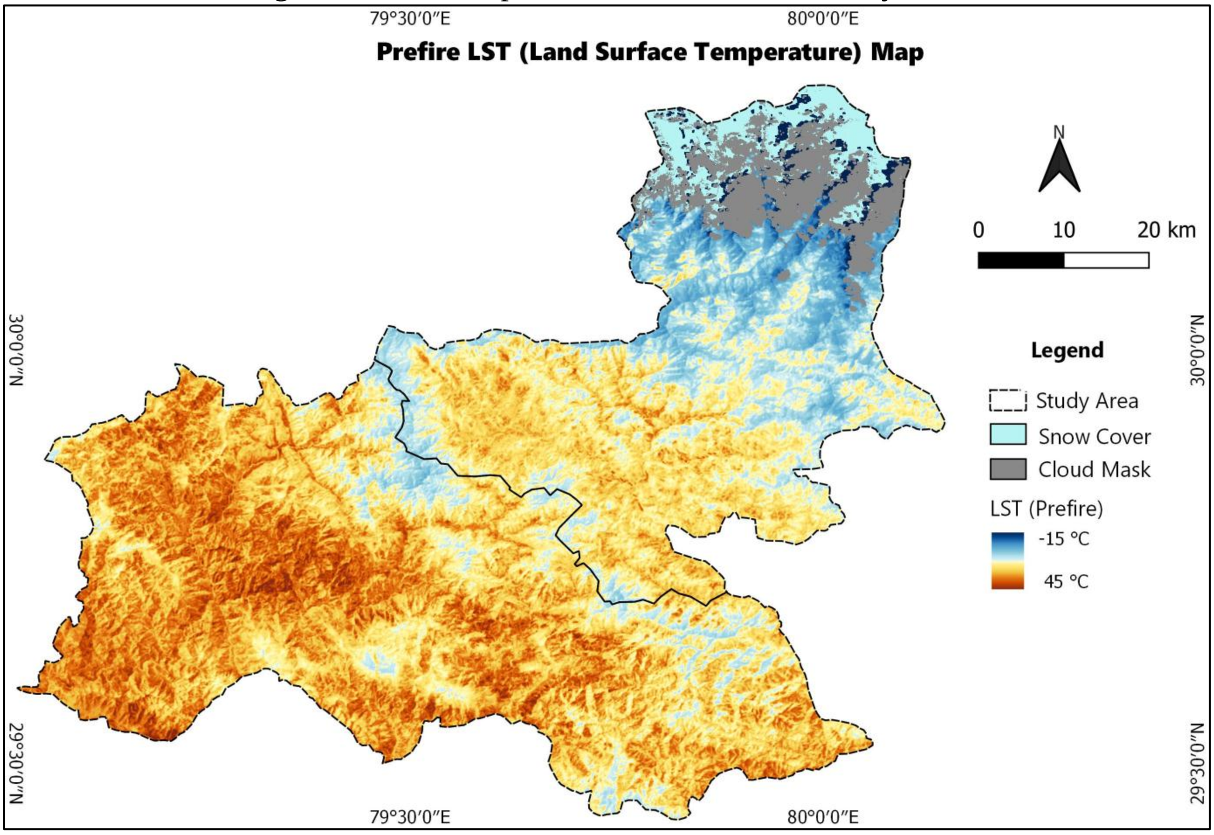


Figure 4. LST Map of Prefire scene of the study area

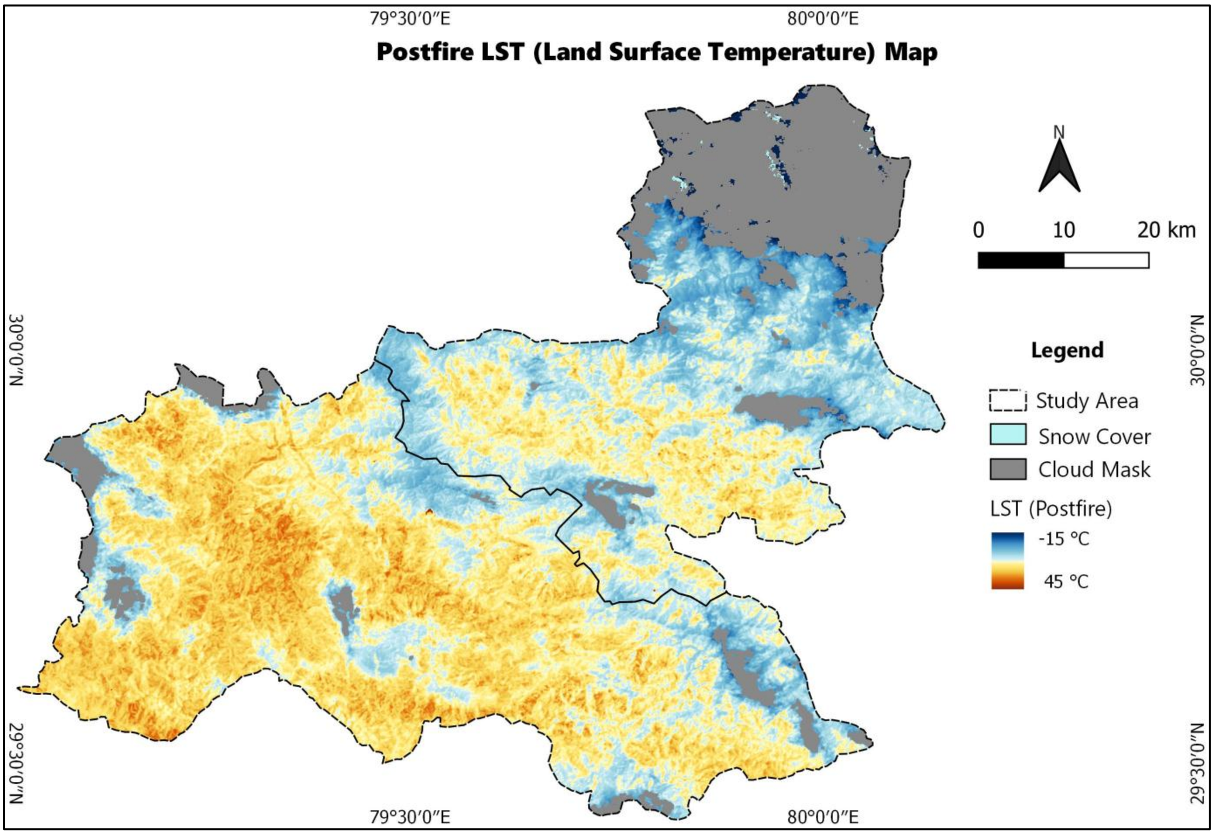


Figure 5. LST Map of Postfire scene of the study area

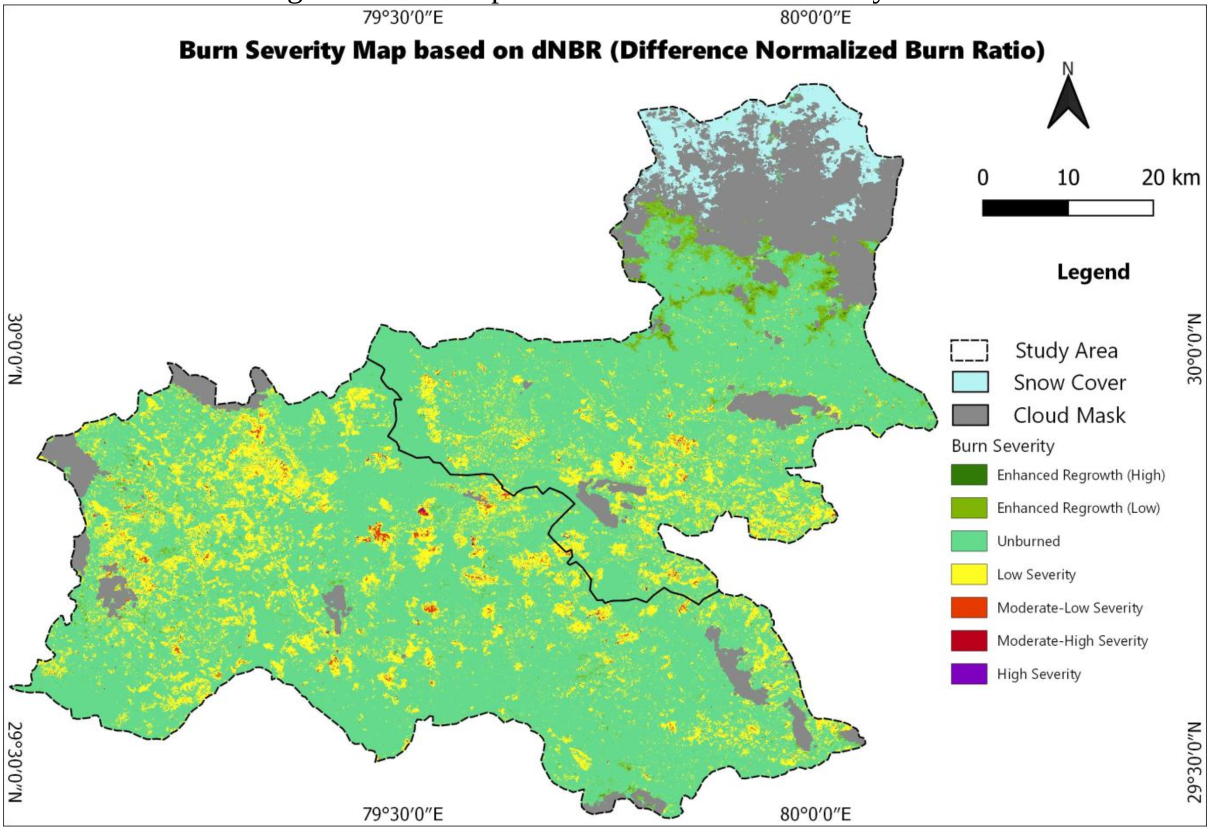


Figure 6. dNBR based Burn Severity Map of Postfire scene of the study area.

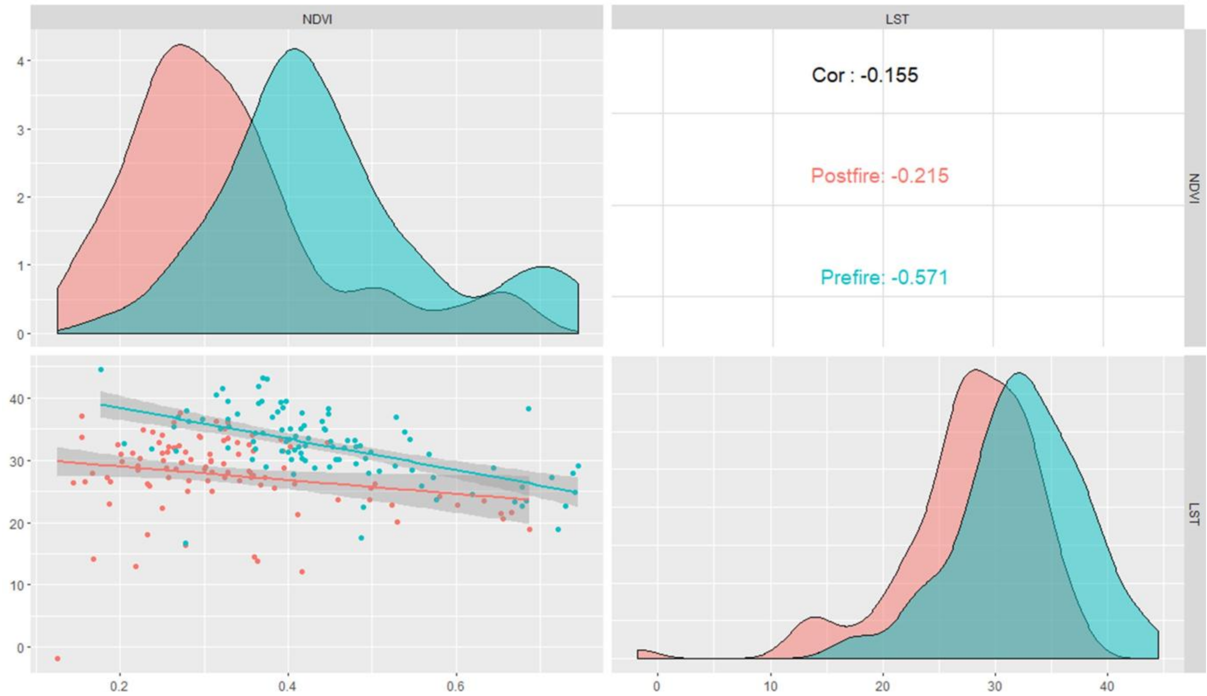
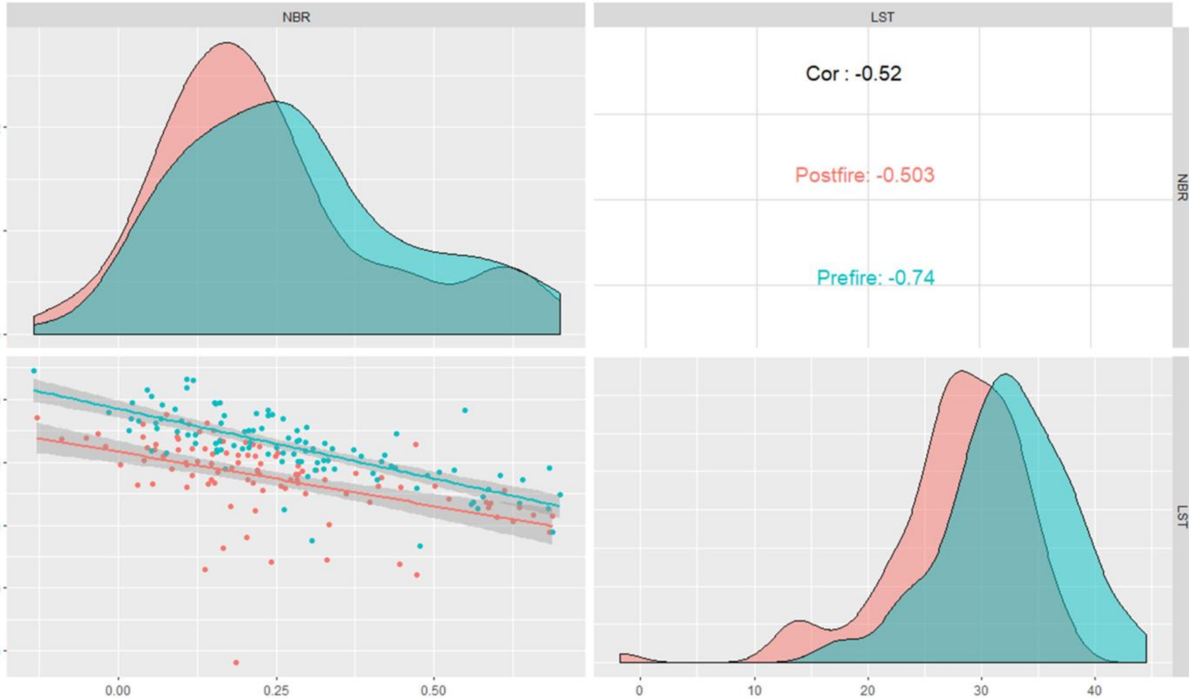


Figure 7. Correlation Matrix for NDVI-LST Relation



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