MAPPING OF FOREST FIRE BURNED SEVERITY USING THE SENTINEL DATASETS

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Commission V, SS: Disaster Monitoring, Damage Assessment and Risk Reduction

KEY WORDS: Sentinel, Forest fire, NBR, dNBR, RBR

ABSTRACT:

Forest fires are frequent phenomena in Uttarakhand Himalayas especially in the months of April to May, causing major loss of valuable forest products and impact on humans through the emissions and therefore effects the climate change. The major forest fire was started on May 19, 2018 and spread in 10 districts out of 13 districts of Uttarakhand state till the fire was suppressed after May 30, 2018. The burned area mapping is essential for the forest officials to plan for mitigation measures and restoration activities after the fire season. In this study, sentinel 2A & 2B satellite datasets were used to map burned severity over Uttarakhand districts. Differentiated Normalized Burn Ratio (dNBR) and Relativized Burn Ratio (RBR) were calculated and compared with the active fire points. Results shows that both the dNBR and RBR are in good agreement with the actual occurrence of forest fires.

1. INTRODUCTION

The burned area mapping is essential for the forest officials to plan for mitigation measures and restoration activities after the fire season. Rapid and accurately mapping of fire burn severity is an essential initiative to support fire management activities such as strategic planning, mitigation measures and monitoring restoration of vegetation (Garcia and Caselles, 1991; Key and Benson, 1999; Michalek et al., 2000; Key and Benson, 2006; Parks et al., 2014). In the management of forests, it is necessary to analyze the impact of fire on the ecosystem. Burn severity can be defined as the degree of change in the vegetation and soil constituents due to the fire (Miller and Thode, 2007). Burn severity is an important parameter for predicting the vegetation structure and the regrowth restoration (Johnstone and Chapin, 2006; Macdonald et al., 2007). It is very difficult to map burn severity using traditional methods, especially in the case where terrain has complex topography and inaccessible areas. Currently there is a wide range of satellite based products from medium (30 m) to high (10 m) spatial resolution that makes it possible to accurately map the burnt areas from regional to local levels. However, the increase in spatial resolution results in a decrease in temporal resolution and vice versa, which results in small burnt areas being left out. Studies carried out by several researchers across the world suggests that, burn severity mapping is more effective when the ratio, that combining near infrared and shortwave infrared of the electromagnetic spectrum because the burnt area show higher reflectance than the green vegetation in Short Wave Infra-red Region (SWIR) (Garcia and Caselles, 1991; Key and Benson, 1999; Parks et al., 2014). Burn severity mapping with high spatial resolution has been carried out with Landsat series satellite imagery (Chuvieco and Congalton, 1998; Michalek et al., 2000) and the ‘LISS-3’ sensor of the IRS Indian satellite occasionally (Chuvieco and Congalton, 1998). Recently, Optical satellites of medium spatial resolution satellites such as Landsat 8 OLI (30m), IRS P6 AWIFS (56m) have been using across the world to map burnt areas (Garcia and Caselles, 1991; Key and Benson, 2006). In general, burn severity is most effective when the spectral ratio that combines both the NIR and SWIR bands and successful if applied to the satellite images acquired before and after the fire event (Garcia and Caselles, 1991; Key and Benson, 2006; Parks et al., 2014). In most of the studies, Normalized Burn Ratio (NBR) has been calculated from the NIR and SWIR bands and dNBR ( differenced NBR) has been used for the mapping of burn severity. Relativized Burn Ratio (RBR) was proposed as an alternative to dNBR and showed the improvement than dNBR (Parks et al., 2014). In this study, dNBR and Relativized Burn Ratio (RBR) have been used for generating the burn severity and compared the results for the sentinel datasets.

In this study, sentinel 2A & 2B satellite datasets were used to map burned severity over the Pauri Garhwal and Tehri Garhwal districts of Uttarakhand, India. Both the Sentinel 2 satellite and Landsat 8 data are freely available for download, however, the sentine2 satellite data has higher spatial resolution (10m, 20m) than Landsat 8 OLI datasets (30 m) and also the revisiting period of combined Sentinel 2A and 2B is 5 days when it comes to Landsat 8 of 16 days. Therefore, the Sentinel 2A and 2B satellite datasets were used to generate the burn severity map in this study.

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2. STUDY AREA AND DATASETS

The study area chosen as the Pauri and Tehri Garhwal districts of Uttarakhand state, which was covered in Sentinel 2A and 2B on the nearest dates of both the pre and post fire event i.e. 11 May, 2018 and 20 May 2018 of major fire episode.

3. METHODOLOGY

Sentinel 2A and 2B satellite data sets of pre and post fire episode was downloaded and consists of 13 spectral bands of varying spatial resolutions from 10 m to 60 m. The spectral bands were preprocessed to get the geometric corrected TOA reflectance bands. In this study, Bands 3, 8 and B12 were used to map the severity of burnt area. The Bands 3 and 8 are having 10 m spatial resolution, therefore these two bands were resampled into 20 m to match with the spatial resolution of band 12. Fig 1 shows the methodology flow to generate the burn severity map.

After resampling the Bands 3 and 8 to 20m, Normalized Burn Ratio (NBR) for the pre and post fire event were calculated. The NBR has been used to highlight the burnt areas, and is calculated from the NIR and SWIR bands, in case of sentinel, bands 8 and 12 were used (Key and Benson, 1999). Cloud mask has been used to remove the cloud pixels in the bands and NBR is calculated by using the equation 1 for sentinel 2A and 2B satellites.

\[ NBR = \frac{\text{Band} 8 - \text{Band} 12}{\text{Band} 8 + \text{Band} 12} \]  

Generally, NBR values are ranging from -1 to +1. Healthy vegetation has very high reflectance in NIR region, where as the burnt areas show low reflectance. In contrast, burnt areas show higher reflectance and healthy vegetation show lower in SWIR region. Therefore, the higher NBR value indicates healthy vegetation and lower value for burned areas.

\[ NDWI = \frac{\text{Green} - \text{NIR}}{\text{Green} + \text{NIR}} \]  

\[ NDWI_{\text{Sentinel}} = \frac{B_3 - B_8}{B_3 + B_8} \]  

Water bodies in the image can show similar spectral reflectance as burnt areas, therefore, water pixels mask out in both the pre and post fire season. The Normalized Difference Water Index (NDWI) was used, to highlight the water body pixels (McFeeters, 1996).

\[ \text{dNBR} = \text{NBR}_{\text{pre fire}} - \text{NBR}_{\text{post fire}} \]
Relativized Burn Ratio (RBR) \cite{Parks2014} is the ratio of 
dNBR to pre fire NBR adjustment and can be calculated by using 
the equation (5).

\[
RBR = \frac{dNBR}{(NBR_{\text{prefire}} + 1.001)}
\] (5)

In the denominator of Eq (5), 1.001 is added to ensure that the 
denominator will never reach to zero \cite{Parks2014}.

### 4. RESULTS AND DISCUSSION

The resultant dNBR map was multiplied by a scale factor 1000 
to categorize the fire severity levels. United States Geological 
Survey (USGS) proposed 7 interpretation levels based on the 
dNBR value \cite{un-spider.org} and is shown in Table 1 and Burn 
severity map was generated by reclassifying the dNBR map on 
the basis of Table 1.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Severity Level</th>
<th>dNBR range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Enhanced Regrowth, High</td>
<td>-500 to -251</td>
</tr>
<tr>
<td>2</td>
<td>Enhanced Regrowth, Low</td>
<td>-250 to -101</td>
</tr>
<tr>
<td>3</td>
<td>Unburned</td>
<td>-100 to 99</td>
</tr>
<tr>
<td>4</td>
<td>Low Severity</td>
<td>100 to 269</td>
</tr>
<tr>
<td>5</td>
<td>Moderate-Low Severity</td>
<td>270 to 439</td>
</tr>
<tr>
<td>6</td>
<td>Moderate- High Severity</td>
<td>440 to 659</td>
</tr>
<tr>
<td>7</td>
<td>High Severity</td>
<td>660 to 1300</td>
</tr>
</tbody>
</table>

Table 1. Burn severity levels (USGS)

A Field-based composite burn index was used to compare the 
dNBR ratios in some of the studies \cite{Warner2017, Fraser2013, KV2017}. Several researchers across the world have used the 
satellite derived active fire points as a proxy for the actual occurrence of fires \cite{Chuvieco2008, Adab2013, Babu2016a, Babu2016b}. Active fire points were taken as a proxy for the 
ground fire points as it is very difficult to cover and take the 
ground fire points data in the study area due to the hilly and rugged terrain \cite{Babu2016a, Babu2016b}. Active fire hotspot product 
MODIS TEERRA and AQUA thermal anomaly product \cite{MCD14} and VIIRS product \cite{VNP14MGTDL} during the fire 
event were downloaded over the study area from the Fire 
Information for Resource Management System (FIRMS) website 
(https://firms.modaps.eosdis.nasa.gov/). These are the actively 
burning fires during the time of satellite overpass. Active fire 
points are overlaid on the burn severity map to check the 
accuracy of the burn severity map. Fig 3 shows the Burn severity map over the study area. In the burn severity map, it was assumed 
that fires fell in low to high severity levels were categorized as 
burnt class and the rest of them are un-burnt. Number of fire 
points fell in the burnt and unburnt classes were extracted and Fig 
4 shows the number of fire points fell in these two classes and it 
was evident that the maximum percentage (81.5\%) fires fell in 
burnt class.

Relativized Burn Ratio (RBR) map was generated by using the 
equation (5) and if the value is greater than 0.27 then the class is 
burnt otherwise un-burnt \cite{Parks2014}. The same fire 
points were used for the accuracy of RBR and Fig 5 shows the 
RBR image overlaid with fire points. The percentage of fires fell 
in burnt class is around 83.08\%, i.e. increase in accuracy as 
compared with the dNBR. This is due to the fact that value of 
dNBR is small when the forest areas covered with low vegetation 
because of change between the pre and post fire NBR will be 
small for these areas \cite{Escuin2008, Parks2014}. The 
RBR can determine the burn severity of low vegetation covers 
also. Finally, it was cleared from the above discussion that, 
Relativized burn ratio show higher accuracy than the difference 
Normalized Burn Ratio.

Thus, sentinel 2 satellite datasets will be useful for the mapping 
of burn severity rapidly as compared with the Landsat satellite 
datasets with improved spatial resolution. The temporal 
resolution of combined Sentinel 2 A and 2B datasets is 5 days, 
therefore the burn severity map can be generated within the short 
span of time after the fire incidents.

### 5. CONCLUSION

In this study, sentinel 2A and 2B satellite datasets have been used to 
generate the burn severity map of Uttarakhand districts, India. Sentinel 2A datasets were downloaded for the pre fire event and 
sentinel 2B for post fire event so that the burn severity map was 
genenerated immediately after the event happened. Both the 
sentinel datasets were cloud masked and then applied Normalized 
Difference Water Index (NDWI) for water mask before 
calculating the burn severity as the burnt areas show similar 
reflectance as water bodies. In this study, difference Normalized 
Burn Ratio (dNBR) and Relativized Burn Ratio (RBR) were 
calculated and compared based on the number of active fire 
incidents (MCD14) of that event. The results were showing that 
RBR shown a better accuracy than dNBR because the RBR can 
determine the burn severity of low vegetation covered areas. 
Thus, the sentinel satellite datasets are useful to generate burn 
severity maps in quick time as compared with the Landsat 
satellite datasets due to the high temporal resolution and spatial 
resolution.
Figure 3. Burn severity map and zoomed extent shows the active fire hotspots overlaid on the various severity levels.

Figure 4. Number of fires in burnt classes of dNBR
Figure 5. Relativized Burn Ratio map and zoomed extent shows the active fire hotspots overlaid

Figure 6. Number of fires in burnt classes of RBR

ACKNOWLEDGEMENTS

First author is grateful to Department of Science and Technology (DST), New Delhi, for awarding INSPIRE fellowship. Authors would be thankful to Director IIRS, Dr. Prakash Chauhan for their encouragement. Authors also acknowledge Prof. K S Rajan, Head, Lab for Spatial Informatics, IIT, Hyderabad for their suggestions and support throughout research. The authors acknowledge the use of data products or imagery from the Land, Atmosphere Near real-time Capability for EOS (LANCE) system operated by the NASA/GSFC/Earth Science Data and Information System (ESDIS) with funding provided by NASA/HQ.
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