Recent rise in wildfires in community forests and other natural vegetation: geospatial basis

Wildfire is one of the major natural hazards, and its extent and frequency of occurrence are currently increasing in the warming world. This is augmented with an absence of precipitation over a contiguous and prolonged spell during pre-summer months, leading to rise in skin temperature. Furthermore, the degradation of lignin and cellulose materials in plant leaves increases the efficiency of more readily available fuel for ignition. Grasses and shrubs have low ignition temperature (~270°C)[1]. The non-native and introduced species such as *Eucalyptus* and *Acacia* have relatively lower ignition temperature (~300°C) and shed a lot of litter in early summer with leaves having resinous material that induces inflammation. Further, human-induced or nature-driven ignition supported with wind flow leads to quick initiation of ground fire. Once the fuel with lower ignition temperature is burnt, the fire spreads by fast transfer of heat and raising the ignition temperature of the adjoining green, native vegetation to catch/spread the fire.

Satellite remote sensing offers synoptic and repetitive images providing information on changes in vegetation phenophases as a response to physiological activities. Such changes in physiological responses and vegetation loss due to burning areas are characteristically reflected by different parts of the electromagnetic spectrum. These are well studied using different normalized and differential indices such as the normalized burn ratio (NBR)[2] and plant senescence reflectance index (PSRI)[3]. Land surface temperature (LST) is the measurement of skin temperature of the Earth's surface[4] that determines the risk of wildfire[5]. The burned area shows a low reflectance in Near Infra-Red (NIR) and high in Short Wave Infra-Red (SWIR) region in contrast to healthy vegetation; thereby NBR helps identify the recent burn areas that are represented as negative values[6–8]. The difference between pre- and post-periods provides the differenced NBR (dNBR) that is useful for the burnt area mapping[8] and thresholding helps in automatic extraction of the burnt area. PSRI (=[680 – 500 nm]/750 nm) determines the stages of leaf senescence[3] and thus is used in plant physiological stress detection and health monitoring. PSRI maximizes the sensitivity of the carotenoids to chlorophyll, and an increase in PSRI indicates canopy stress that is represented as positive values.

Table 1 lists the wildfire events that occurred during the past five months. We have exemplified a wildfire event that occurred in the IIT Kharagpur campus (22.3145°N, 87.3091°E) on 25 March 2021 during 1700–2200 h by analysing pre- and post-period satellite data. We witnessed the event on the day of occurrence (Figure 1 *a* and *b*). Two standard false colour composite (sFCC) images of Sentinel-2A on 25 and Sentinel-2B on 30 March 2021 that pass over the burn area are provided (Figure 1 *c* and *d*). Further, using NBR and dNBR, the burned area was mapped[8]. The progressive changes in canopy stress and the corresponding rise in surface temperature were studied through time-series analysis and correlated using PSRI[3] and LST[5].

The time-series Sentinel data were used (https://eos.com/find-satellite/sentinel-2/) for generating NBR and PSRI. Two sFCCs were generated from NIR_{833}, Red_{665} and $Green_{560}$ spectral bands for relative discriminant visualization of burn areas[9]. The NBR ($NIR_{833} – SWIR_{1614}/NIR_{833} + SWIR_{1614}$) for pre- and post-burn periods was generated and dNBR (differenced NBR = pre-fire NBR – post-fire NBR) was derived using a threshold value of >0.25 (ref. 5). MODIS (MYD11A2) eight-day LST with 1 km spatial resolution was analysed from December 2020 to March 2021. This product contains LST, quality assessment, observation time, view angles and emissivities (https://modis.gsfc.nasa.gov/data/dataprod/mod11.php). PSRI ((=Red_{665} – $Blue_{492}$)/Red $Edge_{741}$) and time series of MODIS (MYD11A2) 8-day LST data were generated and plotted using the Google Earth Engine (GEE) platform.

The burn scars were prominently visible in two contiguous dark patches on the sFCC of 30 March 2021 (post-fire period) in comparison to the pre-fire image of 25 March 2021 (morning pass on the burn day) (Figure 1 *d*). The corresponding areas on the pre-fire image were visible as brown patches reflected from the dry and non-green vegetation material, owing to the brown wave (Figure 1 *c*). The NBR image of 30 March 2021 (post-fire period) identified the burned area shown as negative values (Figure 1 *e*). The dNBR generated using a threshold of >0.25 mapped 21.5 ha as the total burn area, distributed over two patches (16.7 and 4.8 ha; Figure 1 *f*). PSRI showed gradual increasing trend from the end of January, indicating canopy stress (Figure 2 *b*), and LST of the two burn patches also showed a rising trend corroborating with the end of January (Figure 2 *c*), attaining a maxima towards the end of March. Figure 2 *d* reveals a strong positive correlation ($R^2 = 0.92$), indicating a directly proportional relationship between temperature rise and vegetation stress.

Climate is the most important variable as it sets suitable conditions for burn if flammable fuel is available. Over the Kharagpur region, there was almost no rain since January 2021, leading to a rise in temperature, leaf senescence and litter accumulation (Figure 1 *a*), subsequently setting an ideal condition for a fire. The wind direction was southwest with 4 km/h speed (https://www.worldweatheronline.com) on the evening 25 March 2021. The burned patches were covered with grasses and scrubs (75%), litters of *Eucalyptus* spp. (20%) and *Acacia* spp. (5%), forming suitable fuel ignition temperature (270°C)[1]. *Eucalyptus* spp. generate about 29–50 tonnes/acre fuel load[10], which is more than any other native trees; and their leaves

Table 1. Major fire events that occurred during December 2020 to April 2021

Location	Date
Dzukou Valley on the Nagaland–Manipur State border	December 2020
Kullu, Himachal Pradesh	January 2021
Simlipal Biosphere Reserve, Odisha	February–March 2021
Namthang, South Sikkim	April 2021
964 locations in Western Himalaya	January–April 2021
Bandhavgarh Tiger Reserve, Madhya Pradesh	March 2021
Pilibhit Tiger Reserve, Uttar Pradesh	April 2021

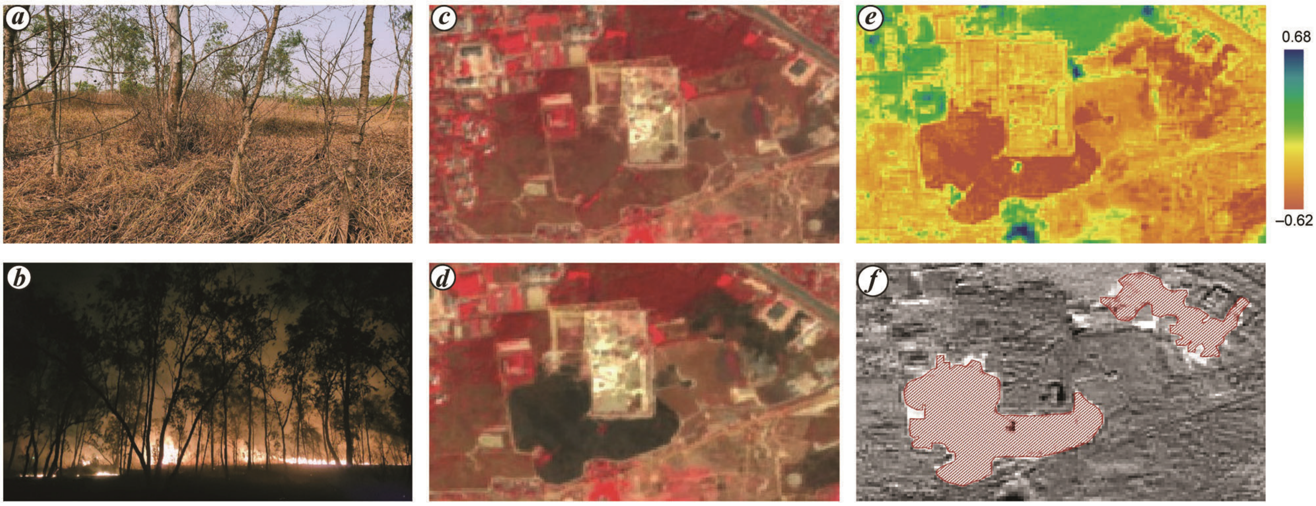

Figure 1. ***a***, ***b***, Field photographs of (***a***) pre-fire fuel condition and (***b***) during fire burn on 25 March 2021. ***c***, ***d***, Standard false colour composite images of (***c***) pre-fire and (***d***) post-fire conditions. ***e***, Normalized burn ratio image of post-fire. ***f***, Burned area identification and mapping using differential NBR.

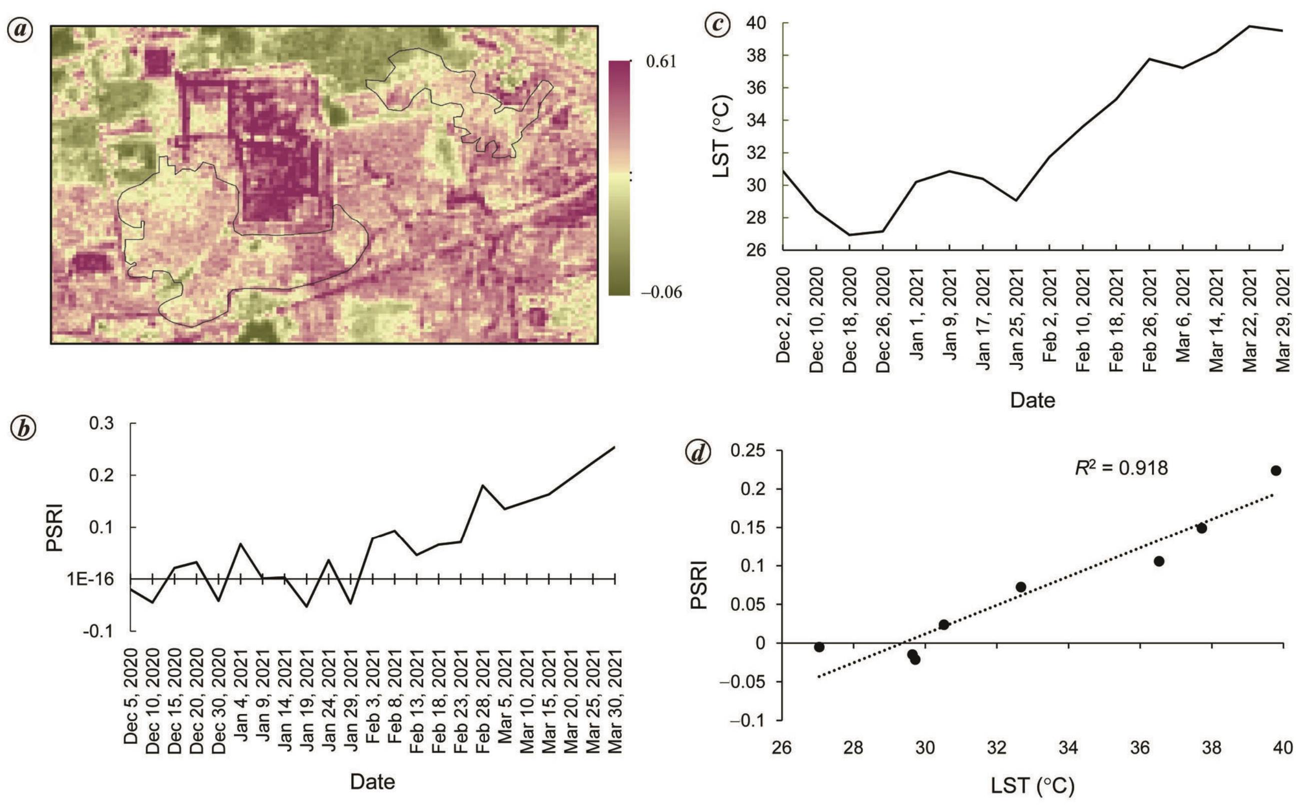

Figure 2. ***a***, Plant senescence reflectance index of 25 March 2021. ***b***, Time series variation during December 2020 to March 2021. ***c***, MODIS-derived land surface temperature (LST) time series variation during the same period. ***d***, Correlation between PSRI and LST demonstrating very high R^2 (0.92).

contain oil allowing to burn faster. *Eucalyptus* spp. with good fuel load, and grasses and scrubs having low ignition temperature increase the risk of fire in combination.

Further, with sudden rise in temperature due to less or no rainfall, more wildfire incidences have been reported this year both within and outside forests. PSRI well demonstrates a rise in canopy stress and dryness over the burn area. This study quickly mapped the burned area using the dNBR threshold, confirming the potential of NBR and dNBR for burned area mapping[11]. The increasing dryness and flammable fuel load were found to be responsible for the wildfire event. The PSRI and LST data analysis implied that the wildfire event occurred during the red-flagged days when all the necessary dry vegetation, low ignition temperature and strong winds were available. The wildfire events close to settlements pose significant danger to life and property. We suggest judicious replacement of non-native species with native plants. Though it may sound impractical in established community forests as they serve multiple benefits, the recent rising trend in wildfire events is a cause of concern.

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