Article

Forest Fire Danger Index Based on Static and Dynamic Parameters Using Satellite Datasets

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Abstract: Forest fire is a major ecological disaster, which has economic, social and environmental impacts on humans and also causes the loss of biodiversity. Forest officials issue the warnings to the public on the basis of fire danger index classes. There is no fire danger index for the country India due to the sparsely distributed meteorological stations. Previous studies suggest that Static Fire Danger Index (SFDI) as well as Dynamic Fire Danger Index (DFDI) have been derived from the satellite datasets. In this study, we have made an attempt to integrate both the Static and Dynamic fire danger indices and also used the Near Real Time (NRT) data sets that can be available for download through NASA FTP server after one hour of the satellite overpass. In this study, DFDI has been calculated from the MODIS Terra NRT Land Surface Temperature (MOD11_L2) and MODIS TERRA NRT surface reflectance MOD09. Finally, The Forest Fire Danger Index (FFDI) has been developed from the static and dynamic fire danger indices by the additive model and the overall accuracy was around 81.27%. Thus, the FFDI has been useful to predict the fire danger accurately and can be useful anywhere, where the meteorological stations are un-available.

Keywords: Forest fire danger index; MODIS; MOD11; MOD09; MOD14

1. Introduction

Forest fires cause extensive damage to the forest resources, environment, humans and property across the world. The forests of Uttarakhand are prone to forest fires, causing loss of biodiversity and degradation of the environment [1, 2]. A major consequence of forest fires is their potential effects on climate change. Most of the valuable plant and animal species are depleted due to the frequent occurrence of forest fires. Emissions from forest fires consists of greenhouse gases such as CO, NOx and organic components, causes a health risk to humans, residing close proximity to forest fire locations [3].

The near real time fire alerts are being generated at National Remote Sensing Centre (NRSC), Earth station using the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor on TERRA & AQUA satellites and Visible Infrared Imaging Radiometer Suite data from the Suomi National Polarorbiting Partnership (SNPP-VIIRS). Active fire location information is disseminated to Forest Survey of India (FSI), state forest departments within half an hour after the satellite overpass and also uploaded on the ISRO BHUVAN website. But till date operational fire danger rating system has not been developed in India except zonation of risk areas in protected areas.

The Fire Danger indices are used as a tool for the decision makers to issue the warnings to the public, based on the level of fire danger classes i.e. No danger, Low, Moderate, High and very High for implementing the mitigation measures to control the fires. The Fire Danger index is an integration of both the dynamic and static fire danger indices. Different fire danger rating systems have been using around the world like. McArthur Forest Fire Danger Index (FFDI) [4], in the eastern parts of Australia, the Forest Fire Behavior Tables [5], in Western Australia, the Fire Weather Index [6] in Canada, the National Fire Danger Rating System [7] in the USA, European Forest Fire Information System [8] in the Europe. These operational fire danger rating systems require hourly, daily meteorological station parameters such as air temperature, relative humidity, rainfall, wind speed and also ground data parameters. There are very few meteorological stations to cover the entire forests of India. So, the operational fire danger rating systems has not been developed in India.

In this study, an attempt has been made to develop the Forest Fire Danger Index (FFDI) by integrating the static and dynamic fire danger indices. The Dynamic Fire Danger Index (DFDI) has been calculated by using the Near Real Time (NRT) MODIS TERRA satellite datasets that can be available after half an hour of the satellite overpass. The Integrated FFDI maps can be disseminated in near real time to the fire managers, take necessary action to control the forest fires.

2. Study area and satellite datasets

The state of Uttarakhand is one of the northern states of India. It shares international boundary with China in the north and Nepal in the east. It has an area of 53,483 Km2 and lies between 28°43' N to 31°27' N latitude and 77°34' E to 81°02' E longitude. Uttarakhand has the recorded forest area of 34,651 Km¬2, which constitute 64.79 % of its geographical area [9].

MODIS is one of the widely used satellite sensors on board NASA TERRA and AQUA satellite datasets that scientists have been using for global and regional studies [10]. Table 1 shows the datasets used in this study to develop the FFDI.

Table 1. Satellite datasets

Name of Datasets	Product ID	Spatial Resolution	Temporal Resolution
Land Surface Temperature	MOD11NRT	1 km	Daily
Surface Reflectance	MOD09GA NRT	500 m	Daily
Land cover type	MCD12Q1	500 m	Yearly
Digital Elevation Model	ASTER	30 m	-
Fire and Thermal Anomalies	MOD14	1 km	Daily

3. Methods

Fire danger indices are have been using across the world, which takes into consideration of all the factors affecting the fire danger and indexing into different classes of fire danger viz. No danger, Low, Moderate, High and very High for the purpose of issuing warnings to the public, implementing the mitigation measures for controlling fires. The Fig 1 showing the methodology developed in this study.

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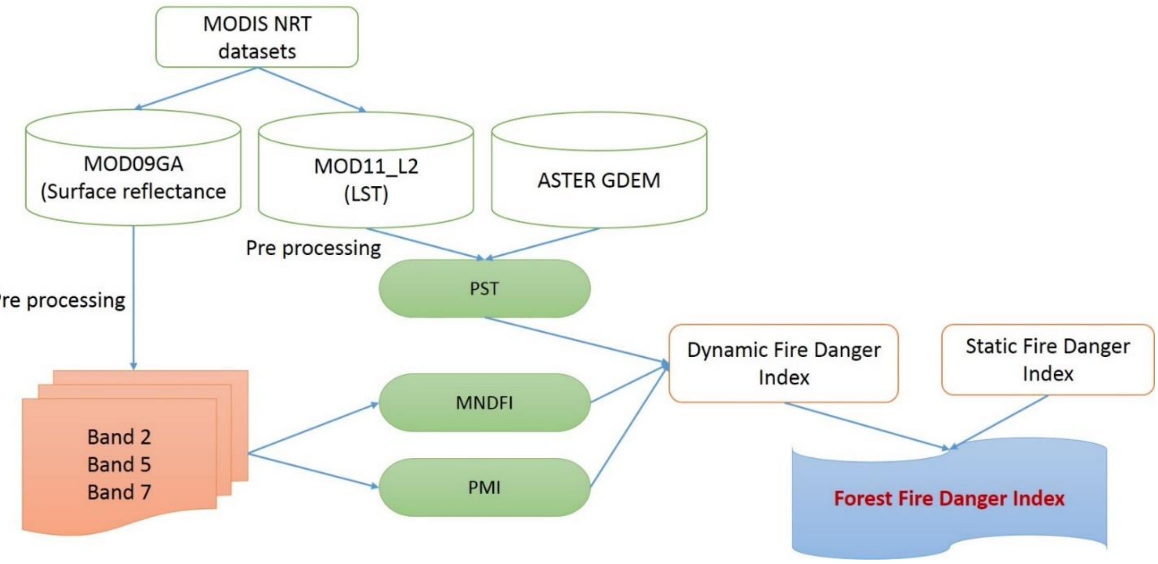

Figure 1: Flow chart showing the methodology

3.1. Dynamic Fire Danger Index (DFDI)

The Dynamic Fire Danger Index has been developed from three parameters such as potential surface temperature, Perpendicular Moisture Index and Modified Normalized Difference Fire Index, which were derived from the MODIS TERRA and ASTER DEM satellite datasets in our previous study [11]. Potential Surface Temperature (PST) that means terrain corrected temperature has been computed from the Near Real Time (NRT) Level 2 MODIS Terra Land Surface Temperature datasets (MOD11_L2) and ASTER GDEM using the Barometric formula. MODIS TERRA NRT surface reflectance dataset MOD09 has been used for generating the Perpendicular Moisture Index (PMI) and Modified Normalized Difference Fire Index (MNDFI).

The main difference from our previous work is temporal resolution of the datasets and the processing level of satellite datasets. In this study, we used the Near Real Time datasets instead of the 8 day composite datasets. These Near Real time datasets are available within 3 hours of the observation time of satellite overpass, downloaded through an FTP website [12]. In this study, Individual parameters were computed and have assigned the values from 1 to 5 based on the danger classes. The dynamic fire danger index has been computed by adding the individual parameters i.e. PST, PMI and MNDFI. Calculation of these parameters were explained briefly.

Potential Surface Temperature i.e. Terrain corrected temperature has been computed from the LST, which has been derived from the MOD11_L2 product and ASTER GDEM.

$$\boldsymbol{p = p_0\left(1 - \frac{Lz}{T_0}\right)^{\frac{g.M}{R.L}}} \quad (1)$$

Where p: Atmospheric pressure; p_0: Standard atmospheric pressure at mean sea level (101.3 kPa); z: Elevation above mean sea level i.e. Elevation generated from the ASTER DEM; L is Temperature lapse rate (0.0065 K/m); R: Gas constant (8.31447 J/ mol-K); g: Earth-surface gravitational acceleration (9.80665 m/s2); M: Molar mass of dry air (0.0289644 kg/mol) and T_0: sea level standard temperature (20°)

$$\theta_s = T_s\left[\frac{p_0}{p}\right]^{\frac{R}{C_P}} \quad (2)$$

Where T_s: Land Surface temperature (in K); R: Gas constant (287 J kg-1 K-1); C_P: Specific heat capacity of air (~1004 J kg-1 K-1) and θ_s: Potential surface temperature (in K).

Perpendicular Moisture Index (PMI) [13] has been used for measuring the live fuel moisture content in the vegetation and can be computed from the equation (3) using the MODIS Bands 2 and 5.

$$PMI = -0.73(Band\ 5 - 0.94\ Band2 - 0.028) \quad (3)$$

Modified Normalized Difference Fire Index can be determined from the following formula [14}.

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$$MNDFI = \left[\frac{Band\ 7 - Band\ 2 - 0.05}{Band\ 7 + Band2 + 0.05}\right] \quad (4)$$

3.2. Static Fire Danger Index (SFDI)

The Static Fire Danger Index has been derived from the static parameters i.e. fuel, topographic and terrain characteristics, which are influencing the spread of forest fires. The Static fire danger index has been developed by integrating the five distinct danger indices, i.e. Fuel type danger index, TRI danger index, Slope danger index, Aspect danger index and Elevation danger index and categorized into fire danger classes viz. No fire, Low, Moderate, High and Very high [15].

4. Results and Discussions

Forest Fire Danger Index (FFDI) has been computed by integrating the static fire danger index and individual dynamic forest fire danger index on each day during the major fire episode of Uttarakhand in 2016. The FFDI has been categorized into 5 fire danger classes such as Very high, High, Moderate, Low and No fire danger and Table 2 shows the value of forest fire danger and the corresponding danger classes. MODIS active fire product MOD14 has been used for the validation. MODIS active fire hotspots have been used for validating the fire danger model in various studies as a proxy for the actual occurrence of fires [16-19]. Fig 2 shows the computed FFDI images overlaid with corresponding active fire hotspots, downloaded from the NASA FIRMS website [20].

Table 2: Fire danger classes assigned to fire danger index

S No	Forest Fire Danger Index value	Danger class
1	<4	No fire danger
2	5-8	Low
3	9-12	Moderate
4	13-16	High
5	>17	Very High

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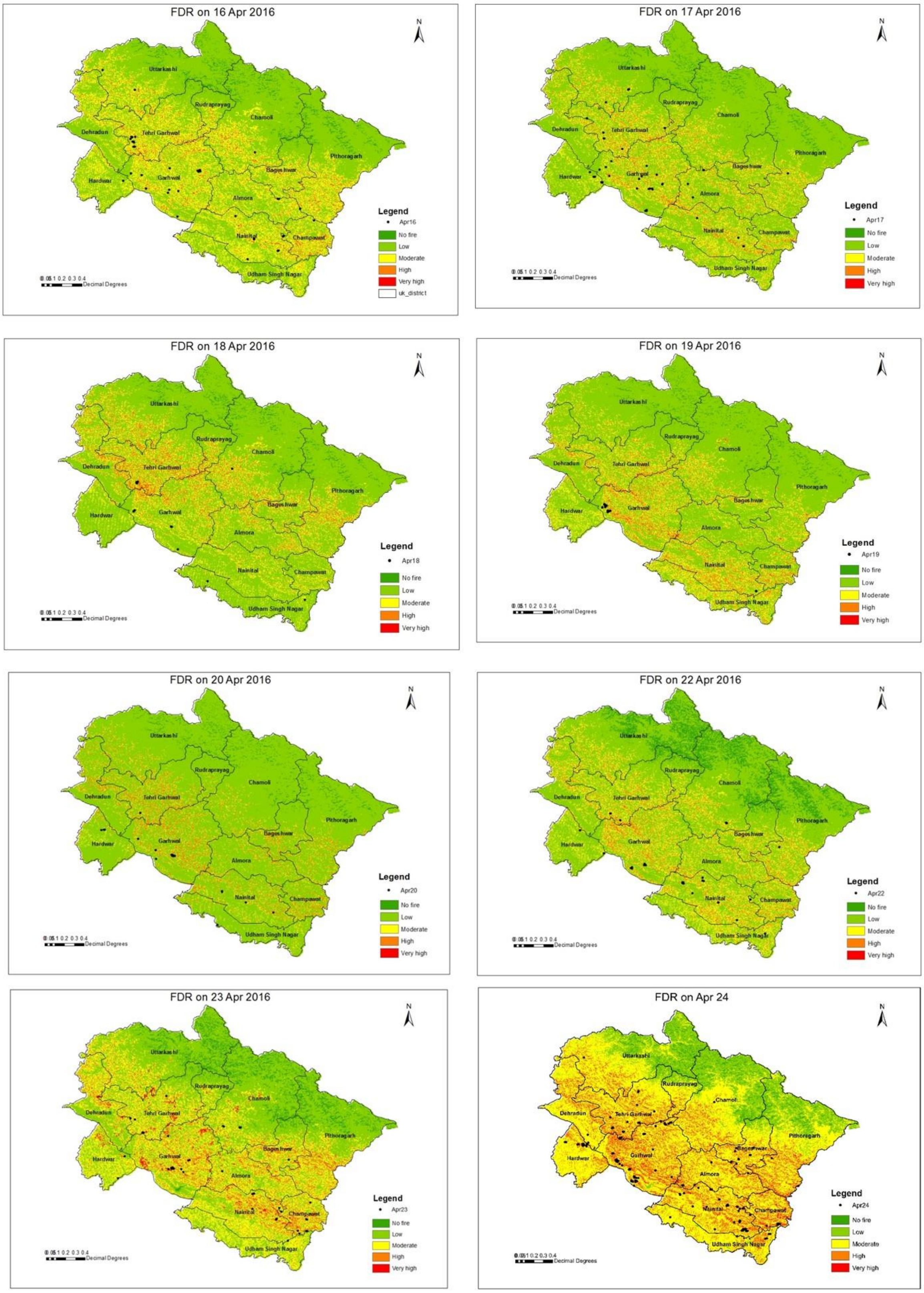

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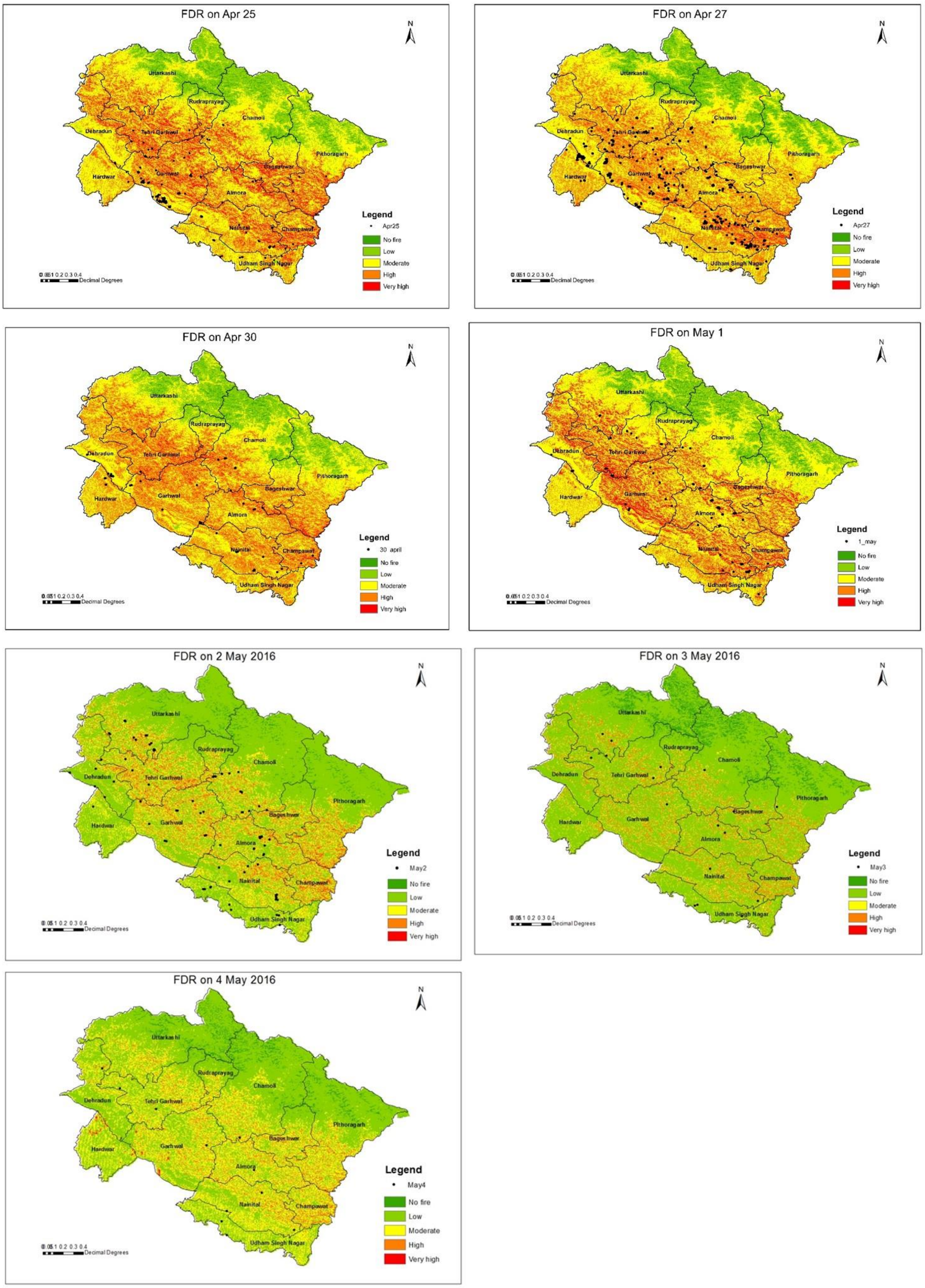

Figure 2: Generated FFDI overlaid with active fire points

Accuracy was estimated on the basis of the number of fires fell in different fire danger classes and using the equation (5) [11, 15].

$$Accuracy\ (\%) = \frac{Active\ fires\ fell\ in\ High\ and\ very\ high\ fire\ danger\ classes}{Total\ number\ of\ active\ fire\ points\ on\ that\ day} \quad (5)$$

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In general, the accuracy of the developed fire danger index depends on the number of fires fell in very high and high fire danger classes and estimated accuracy was ranging from 72% to 91% and the overall accuracy was around 81.27%. Therefore, the developed Forest Fire Danger Index will be useful for the disseminating the danger maps daily in near real time basis using the MODIS TERRA Near Real Time datasets so that the fire officials to take necessary actions to control the spreading of forest fires.

5. Conclusions

In this study, Forest Fire Danger Index (FFDI) has been developed from the static fire danger index and dynamic danger index using the Near Real Time MODIS TERRA datasets. The Forest Fire Danger Index has been developed by integrating the static fire danger index and dynamic fire danger index and computed accuracy was ranging from 72% to 91% and an overall accuracy was around 81.27%. Thus, the developed index has the potential for predicting the forest fires using the satellite derived products.

FFDI has been computed from the near real time datasets, which can be downloaded from the NASA FTP server after the satellite overpass. The entire procedure is automated sequentially i.e. downloading, preprocessing, generating the intermediate parameters and finally computing the Forest Fire Danger Index. Then it will be useful for disseminating the forest fire danger maps to the users for the control activities of forest fires during the fire season.

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Conflicts of Interest: Declare conflicts of interest or state "The authors declare no conflict of interest."

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