Forest fire danger model based on satellite datasets using geo spatial techniques

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ABSTRACT

Forest fire causes major degradation of forests in Uttarakhand and effects severe damage to ecosystem, wild life and human life through harmful green house gas emissions. Forest fire is common feature in Uttarakhand forests above 50% of the forests are prone to fires annually. Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on board NASA Terra and Aqua is useful to detect the active forest fires and monitoring the fires. MODIS derived products MOD09A1 i.e. MODIS Terra Surface Reflectance 8-day L3 Global 500 m SIN Grid products and MOD11A2 i.e. MODIS Terra Land Surface Temperature (LST) and Emissivity 8-day level-3 data on a 1-km Sinusoidal grid were used in this study. Elevation data for the study area was downloaded from ASTER Digital Elevation Model (DEM). Three parameters potential surface temperature, Normalized Multiband Drought Index (NMDI) and Visible Atmospheric Resistant Index (VARI) were computed from the above satellite derived datasets. Fire danger model was developed by imposing threshold criterion on three parameters that forecast the 8th day fire danger. MODIS active fire location data (MOD14) were used for the validation of the model and results showing that accuracy of 85% to 90% fires fell in High to very high danger classes.

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1. Introduction

Forest fire is considered as one of the major cause of degradation of forests in India (Roy, 2000) that cause large scale destruction to the forests ecosystems. Forest fires occur annually ranging from 33% in few states to over 90% in some states in India. According to the recent State of Forests report, the forest cover in India is 692,027 km^2, constituting 21.05 % of its geographical area, represented by 83,471 km^2 (2.54 %) of very dense forest and 320,736 km^2 (9.76%) of moderately dense forest and open forest is 287,820 km^2 (9.76%) (India State of Forest Report, 2011). Studies by Forest Survey of India reveal that on an average 53 % forest cover of the India is prone to heavy to light fire and 6.17% of the forest fires are severe (India State of Forest Report, 2005, Bahuguna et al., 2002; Gubbi, S. 2003, Saklani, 2008). In India majority of fires are started due to humans and natural causes of fires are very less (Bahuguna et al., 2002).

India with collaboration from other international space programmes has its own program in place for detecting and monitoring forest fires in near real time basis. Indian Space Research Organization (ISRO) through its series of Indian Remote Sensing (IRS) satellites, Environment Satellite (ENVISAT) and Defense Meteorological Satellite Program-Operational Line Scan System (DMSP-OLS) - helps in detecting fires during night, monitoring fires and burnt area assessment (Kiran Chand et al., 2006). ISRO established Decision support centre (DSC) at National Remote Sensing Centre (NRSC), Hyderabad to the effective management of disasters in India. A comprehensive system "Indian Forest Fire Response and Assessment System (INFFRAS)" was developed for the effective management of forest fires (NRSA report, 2006; South Asia Disaster Report, 2007). NRSC and Forest Survey of India (FSI) has disseminate forest fire alerts to the forest departments in near-real time on the basis of data received from Moderate resolution imaging spectra radiometer (MODIS) on board TERRA and AQUA satellites and these national Fire alerts are being dispatched to the users within two hours of the satellite pass. India does not have operational forest fire danger rating system till now except few case studies.

Fire danger indices are used in many parts of the world to integrate meteorological and fuel information into a single or small number of measures. These measures can then be applied to regions for the issuing of warnings, or more locally to estimate the challenges to control fires. Fire danger is the resultant of factors either constant or variable that affecting the inception, spread and difficulty of controlling fires and preventing extensive damage (Chandler et al. 1983). If any of above factors is absent, then there is no fire danger (Cheney and Gould1995). The various factors of fuels, weather, topography and risk are combined to assess the daily fire potential on an area and usually expressed in numeric or adjective terms. Fire danger indices are an important tool for fire and land managers. Different fire danger ratings were developed and being using around the world, including the McArthur Forest Fire Danger Index (FFDI) (McArthur 1967) in eastern Australia, the Forest Fire Behavior Tables (FFBT, Sneeuwjagt and Peet 1998) in Western Australia, the Fire Weather Index (FWI, van Wagner 1987) in Canada, the National Fire Danger Rating System (Deeming et al. 1977) in the USA and the Nestrov Fire Danger Index System in the Russia. This study attempts to develop fire danger model to forecast the 8-day fire danger based on the satellite remote sensing derived parameters.

2. Study Area

The state of Uttarakhand is situated in the northern part of India and shares international boundary with China in the north and Nepal in the east. It has an area of 53,483 Km^2 and lies between 28°43' N to 31°27' N latitude and 77°34' E to 81°02' E longitude. The recorded forest area of the state is 34,651 $Km^{2,}$ which constitute 64.79 % of its geographical area (India State of Forest Report, 2011).

According to the reports of forest department, the state Uttarakhand lost 2000 hectares of forests in the year 1998, 60,000 hectares in 1999, 232 hectares in 2000, 1144 hectares in 2001, 3494 hectares in 2002, 4750 hectares in 2003, 4750 hectares in 2004 and 3652 hectares in 2005. In 2006, the State lost 562.44 hectares of forests due to forest fires in 2007; it lost 1595.35 hectares in 2008. In 2012, about 1409 hectares of forests had effected by the fires in the end of the season. According to the forest department of Uttarakhand, Forest fires occur frequently every year during the months of March to June, causing loss to valuable resources and huge damage to forest ecology as well as landscape of the area. So, the effective forest fire management is necessary to mitigate these fires in Uttarakhand. Forest fire managers require early warning system to assist them in implementing fire prevention and management plans.

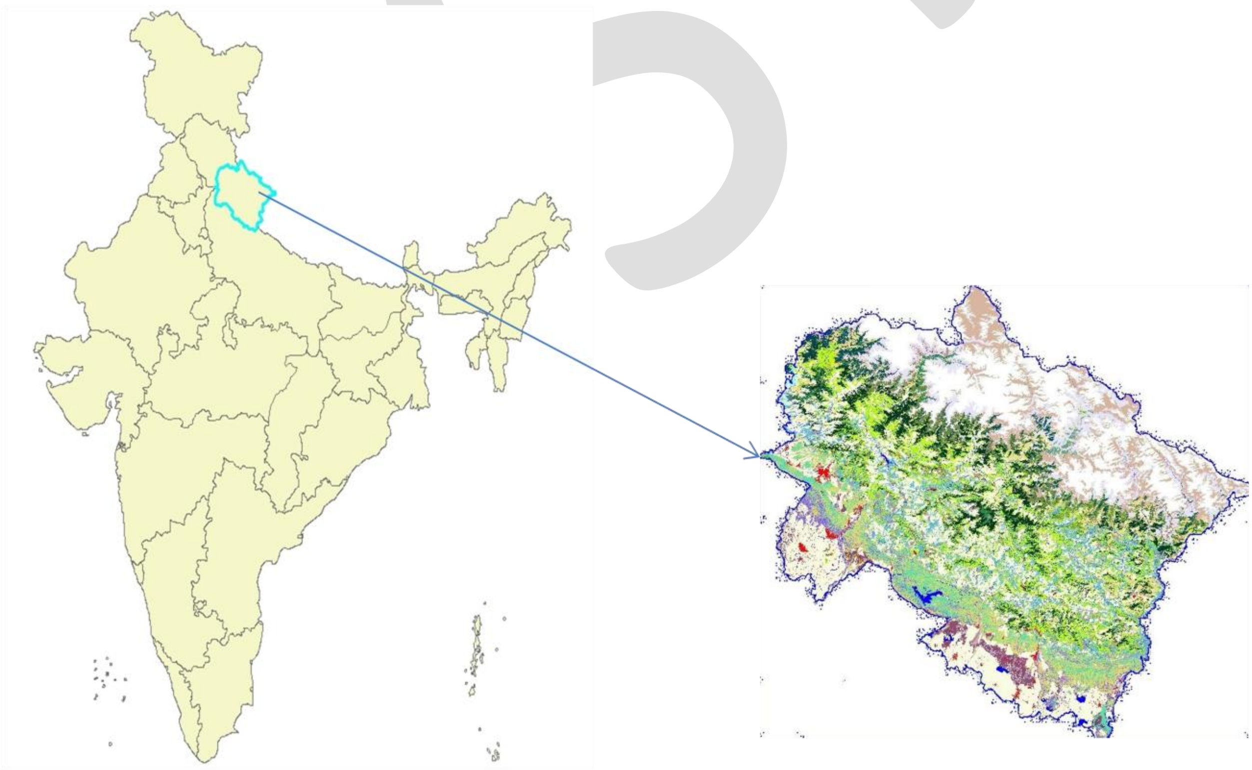

Figure 1: Location of study area

3. MATERIALS AND METHODS

3.1 Satellite Datasets

MODIS (Moderate Resolution Imaging Spectroradiometer) is one of the widely used satellite sensors that scientists are using global and regional studies since 1999. It is a key instrument aboard NASA's Terra (EOS AM) and Aqua (EOS PM) satellites. MODIS will view the entire surface of the Earth every 1 or 2 days, making observations in 36 spectral bands, at moderate resolution (0.25 - 1 km), of land and ocean surface temperature, primary productivity, land surface cover, clouds, aerosols, water vapour, temperature profiles, and fires.

The MODIS TERRA and AQUA surface reflectance products provide an estimate of the surface reflectance of features as it would be measured at ground level in the absence of scattering and absorption. In this study, MOD09A1 i.e. MODIS Terra Surface Reflectance 8-day L3 Global 500 m SIN Grid products were used. MOD09A1 provides bands 1 to 7 at 500-meter spatial resolution in an 8-day gridded level-3 product in the sinusoidal projection. MOD11A2 product provides the level-3 8-day MODIS global Land Surface Temperature (LST) and Emissivity data on a 1-km Sinusoidal grid.

Table 1 shows the information about the satellite datasets used in this study such as product ID, spatial resolution and temporal resolution. MODIS Terra Satellite data sets i.e. MOD09A1, MOD11A2 were 8-day composite datasets were downloaded from the REVERB site () and the entire study area covering the 4 tiles (h24v05, h24v06, h25v05 and h25v06) were processed using HEG tools software and ERDAS imagine software.

ASTER TERRA product (ASTGTM -ASTER Global Digital Elevation Model V002 30m) was downloaded from the REVERB website for the state Uttarakhand (2011) and mosaicked the entire scenes in ERDAS imagine software.

Table 1: Satellite datasets used in the study

S. No	Name of Datasets	Product ID	Spatial Resolution	Temporal Resolution
1	Land Surface Temperature	MOD11A2	1 km	8 day
2	Spectral Reflectance	MOD09A1	500 m	8day
3	Fire and Thermal Anomalies	MOD14	1 km	Daily
4	Digital Elevation Model	ASTER	30 m	-

Downloaded datasets MOD11A2 and MOD09A1 were in Hierarchical Data Format (HDF) and converted to tiff format using HEG tools software for each day during fire season in Uttarakhand (Feb to June) for the year 2013. Table 2 shows the time periods of downloaded

8-day MODIS composite satellite datasets.

Table 2: Time period of 8-day MODIS composite datasets

Julian day	Date
25	25-Jan-2013
33	02-Feb-2013
41	10-Feb-2013
49	18-Feb-2013
57	26-Feb-2013
65	06-March-2013
73	14-March-2013
81	22-March-2013
89	30-March-2013
97	07-April-2013
105	15-April-2013
113	23-April-2013
121	01-May-2013
129	09-May-2013
137	17-May-2013
145	25-May-2013
153	02-June-2013
161	10-June-2013
169	18-June-2013

Six spectral band reflectance data were derived from (500m resolution) from MOD09A1 data using HEG software and these datasets were multiplied by a corresponding scale factor to generate the final data products using Modeler tool in ERDAS software. Finally all the images were clipped (LST and Reflectance products) for the Uttarakhand boundary using ARCMAP software.

Below figure: 2 show the schematic diagram showing the methodology adopted in this study.

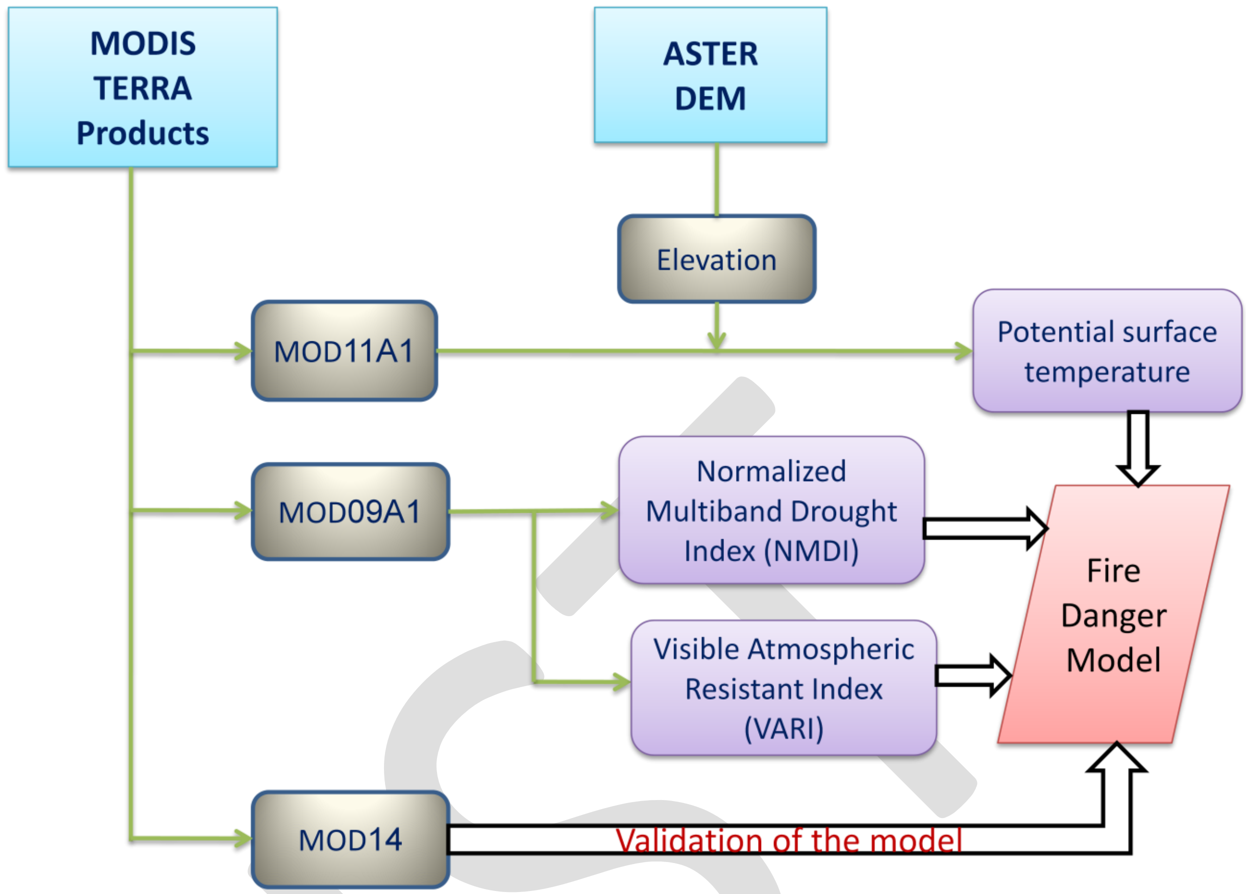

Fig 2: schematic diagram showing the methodology

3.2 Computation of Indices and Parameters

The following parameters were calculated from the above mentioned MODIS and ASTER satellite datasets-

1. Potential Surface Temperature (θ_s)
2. Normalized Multiband Drought Index (NMDI)
3. Visible Atmospheric Resistant Index (VARI)

3.2.1 Potential Surface Temperature: The Land surface temperature (MOD11A2) product was used to calculate the Potential surface temperature using an ERDAS modeler for each day. The following equations were used to compute potential surface temperature. Using Ideal Gas law equation, we find the relationship between Atmospheric Pressure and Digital Elevation Model (DEM) over the study area at every pixel.

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

Where
p: Atmospheric pressure
p_0: Standard atm. pressure at mean sea level (101.3 kPa)
z: Elevation above mean sea level (in m)
L: Temperature lapse rate (0.0065 K/m)

R: Gas constant (8.31447 J/ mol-K)
g: Earth-surface gravitational acceleration (9.80665 m/s^2)
M: Molar mass of dry air (0.0289644 kg/mol)
T_0: Sea level standard temperature

In simplified form, assuming $T_0 = 20°$, Eq 1 can be written as:

$$p = 101.3\left[\frac{293 - 0.0065z}{293}\right]^{5.26} \qquad (2)$$

Pressure data (30m resolution) was converted to 1 km spatial resolution data using Reproject tool in ERDAS. Potential surface temperature was computed using following equation for each day:

$$\theta_s = T_s\left[\frac{p_0}{p}\right]^{\frac{R}{C_P}} \qquad (3)$$

Where,
T_s: 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})
θ_s: Potential surface temperature (in K)

3.2.2 Normalized Multiband Drought Index: Wang and Qu proposed the Normalized Multiband drought index (NMDI) in 2007 to estimate the amount of water content present in soil and vegetation surface (Wang and Qu, 2007). NMDI is a function of soil moisture, so increase of soil moisture leads to the reduction in value and higher values indicate the increasing severity of soil drought. Results from the study carried out by Wang and Qu shows the active fire pixels have the lower values of NMDI than other pixels (Wang and Qu, 2009).

MODIS spectral reflectance bands Band 2, Band 6 and Band 7 were derived from MODIS spectral reflectance data (MOD09A1) and used to calculate NMDI by using following equation (Wang and Qu, 2008, Zarco-Tejada et al. 2003)

$$NMDI = \frac{R_{band\,2} - (R_{band\,6} - R_{band\,7})}{R_{band\,2} + (R_{band\,6} - R_{band\,7})} \qquad (4)$$

3.2.3 Visible Atmospheric Resistant Index: VARI was calculated using Spectral reflectance images (MOD09A1). It was tested by Gittleson et al. in 2002 and computed as

$$VARI = \frac{p_{\lambda_1} - p_{\lambda_2}}{p_{\lambda_1} + p_{\lambda_2} - p_{\lambda_3}} \qquad (5)$$

Where,
p_{λ_1}: Spectral reflectance green (MODIS band 4)
p_{λ_2}: Spectral reflectance red (MODIS band 1)
p_{λ_3}: Spectral reflectance blue (MODIS band 3)

Resultant NMDI and VARI images for each day were converted into 1km spatial resolution using ERDAS Reproject tool.
As discussed earlier methodology, the potential surface temperature, Normalized Multiband Drought Index (NMDI) and Visible Atmospheric Resistant Index (VARI) were computed using Modeler tool in ERDAS Imagine software and the generated datasets were reprojected to 1 km resolution. The resulting images were then clipped to the boundaries of the study area using clipping tool in data management tools in ARCMAP software.

4. RESULTS AND DISCUSSIONS

Fire danger model was developed based on the above three parameters by applying criterion condition in ERDAS software. The model generated images were classified in to 5 fire danger classes i.e. 1. No fire danger 2. Low fire danger 3. Medium fire danger 4. High fire danger 6. Very high danger. Active forest fire locations data (MOD14) were downloaded from the FIRMS website to validate the forecasting model. These point active fire locations were overlaid with fire danger images to determine the accuracy of the model.

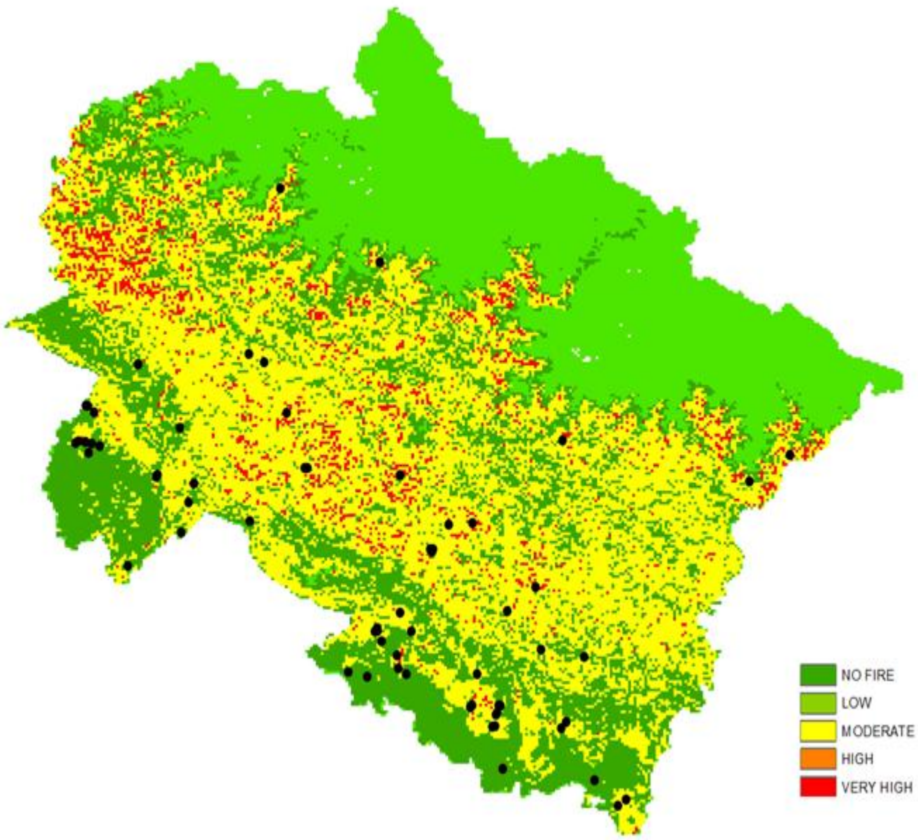

Figure 2: Generated Fire danger map on 26 Feb, 2013 overlaid with Active fire locations on 6 March, 2013

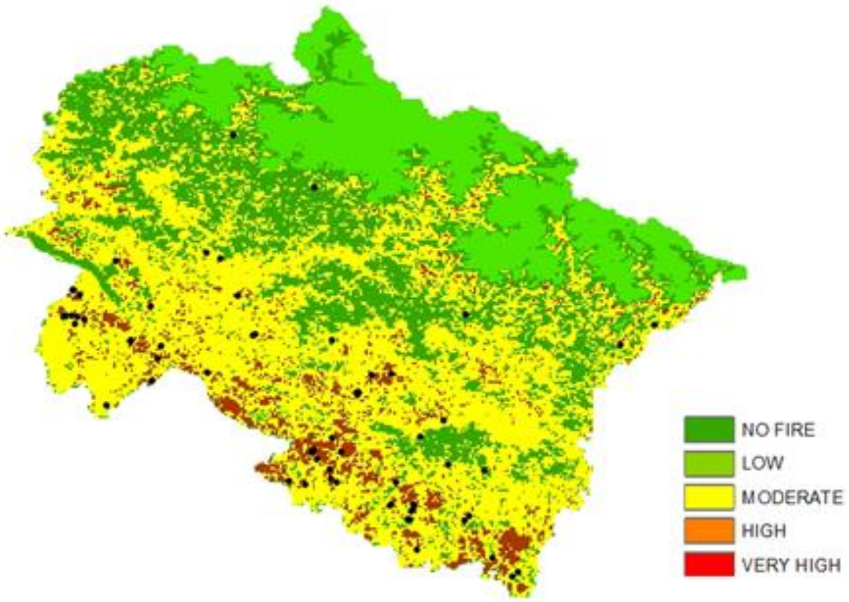

Figure 3: Generated Fire danger map on 6 March, 2013 overlaid with Active fire locations on 14 March, 2013.

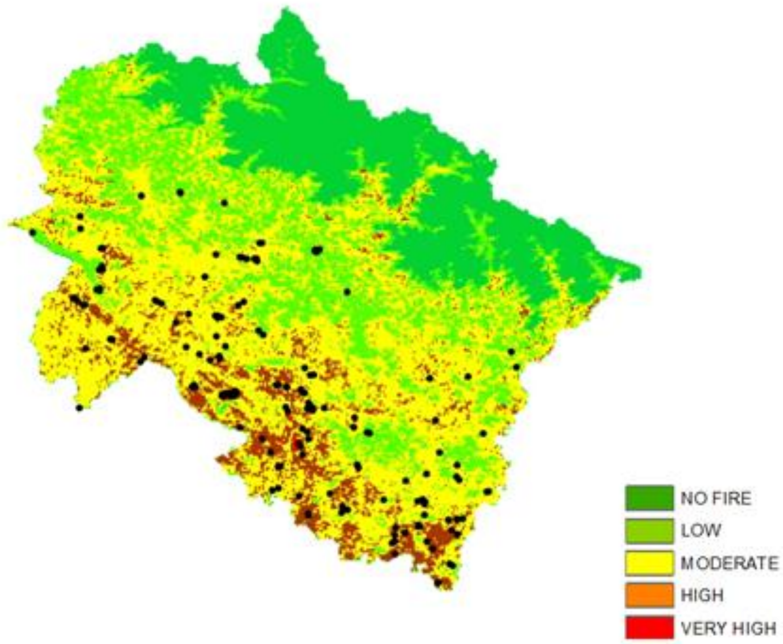

Figure 4: Generated Fire danger map on 22 March, 2013 overlaid with Active fire locations on 30 March, 2013

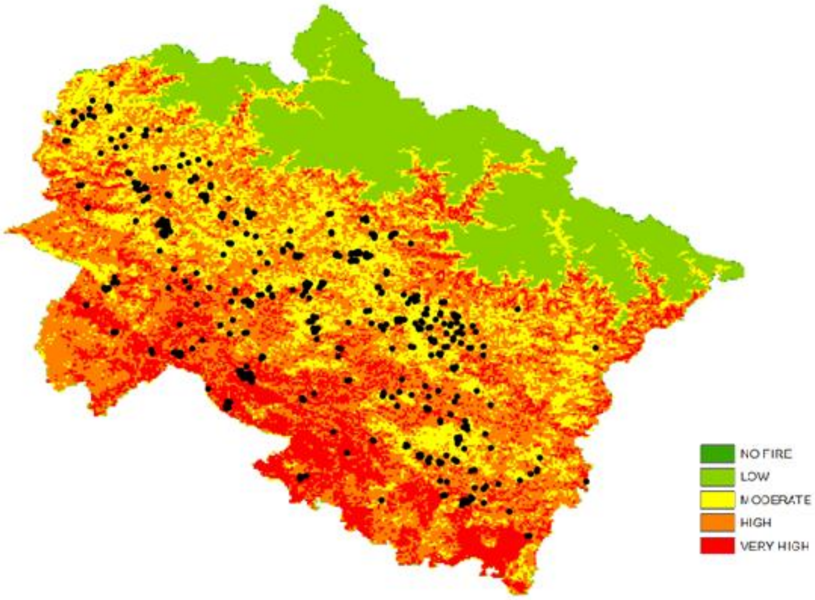

Figure 5: Generated Fire danger map on 15 April, 2013 overlaid with Active fire locations on 23April, 2013

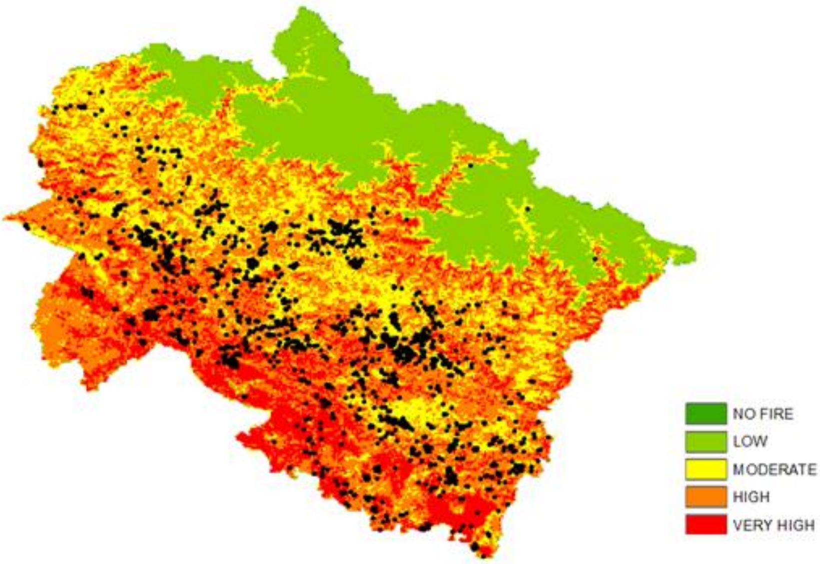

Figure 6: Generated Fire danger map on 9 May, 2013 overlaid with Active fire locations on 17 May, 2013

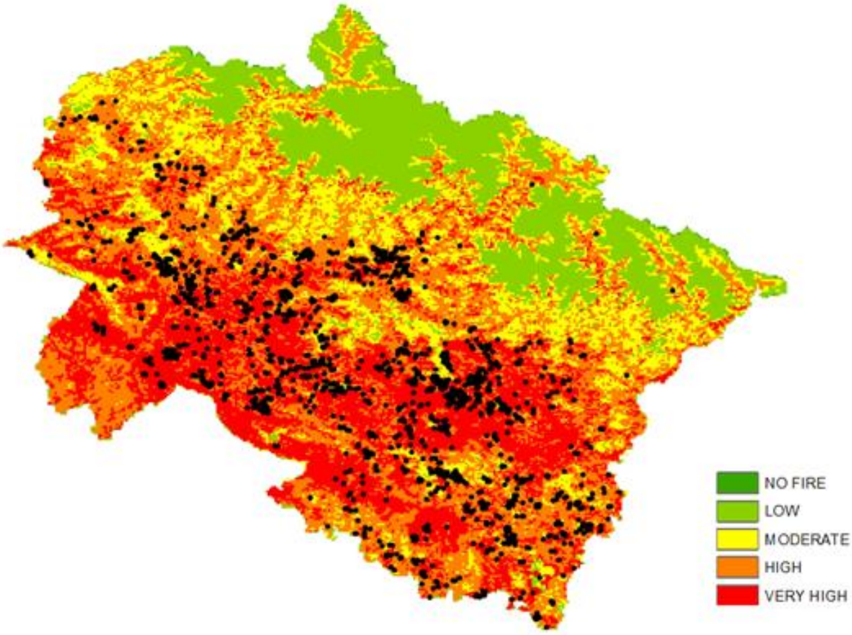

Figure 7: Generated Fire danger map on 25 May, 2013 overlaid with Active fire locations on 2 June, 2013

Accuracy assessment was done for each individual image on the basis of overlaid active fire point locations in ERDAS imagine software. Results were showing that accuracy of 85% to 90% that means most of the fires fell in High to Very High fire danger classes. So, the combination of the parameters Potential Surface Temperature, Normalized Multiband Drought Index (NMDI) and Visible Atmospheric Resistant Index (VARI) accurately modeled the fire danger over the study area.

5. CONCLUSION

This study shows the utility of satellite derived products such as MODIS Terra surface reflectance product (MOD09A1), MODIS Terra land surface temperature (MOD11A2) and ASTER Digital Elevation Model (DEM) for estimating the fire danger. Three parameters potential surface temperature, Normalized Multiband Drought Index and Visible Atmospheric Resistant Index were computed from the above mentioned MODIS and ASTER sensor products. Fire danger model was developed based on the three parameters to forecast the fire danger within 8 day interval. Results were showing that accuracy of 85% to 90% i.e. most of the fires fell in high to very high danger over the study area.

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