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RESEARCH ARTICLE

Forest Fire Burnt Area Assessment in the Biodiversity Rich Regions Using Geospatial Technology: Uttarakhand Forest Fire Event 2016

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Abstract
The hills of Uttarakhand witness forest fire every year during the summer season and the number of these fire events is reported to have increased due to increased anthropogenic disturbances as well as changes in climate. These fires cause significant damage to the natural resources which can be mapped and monitored using satellite images by virtue of its synoptic coverage of the landscape and near real time monitoring. This study presents burnt area assessment caused by the fire episode of April 2016 to the forest vegetation. Digital classification of satellite images was done to extract the burnt area which was found to be 3774.14 km^2, representing 15.28% of the total forest area of the state. It also gives an account of cumulative progression of forest fire in Uttarakhand using satellite images of three dates viz. 23rd, 27th May and 2nd June, 2016. Results were analyzed at district, administrative and forest division level using overlay analysis. Separate area statistics were given for different categories of biological richness, forest types and protected areas affected by forest fire. The burnt area assessment can be used in mitigation planning to prevent drastic ecological impacts of the forest fire on the landscape.

Keywords Forest fire · Uttarakhand · Remote sensing · Burnt area assessment

Introduction

Forest fire is one of the most significant hazard in the forested landscapes. Steep terrain, high summer temperature, high wind velocity and the availability of inflammable material in the forest account for major damage and extensive spread of forest fire (Rothermel 1983; Roy 2003). Forest fire in a mountainous terrain spreads uphill very rapidly. This is caused by the upward flowing hot air resulting in loss of moisture and high temperature in the upper region. Further, Isolated trees at higher altitudes and scrubs at lower altitudes readily catch fire due to less moisture content and presence of high flammability of the coniferous vegetation. Furthermore, rolling and burning forest material promote and reignite fire at new locations down the slopes (Landmann et al. 2015). Pine forests having high content of inflammable resin are also highly susceptible to forest fires. Most of the forest fires are caused by human activities (Bahuguna and Singh 2002). Some fires are accidental but most of the fires are initiated deliberately for some purpose such as to collect Sal seeds left after the forest is burnt, to conceal illegal timber extraction, to improve grass growth, to scare away wild animals, to collect honey or some other reasons including political agitations and community conflicts (Bhandari et al. 2012). The purpose of intentional forest burning differs from region to region in the Indian subcontinent. In north eastern Himalaya, forests are burnt for shifting cultivation. In western Himalaya, forests are burnt to promote fresh fodder growth whereas central Indian forests are burnt to facilitate the collection of non-timber forest products.

Fire, whether natural or anthropogenic, is a widespread and a recurring phenomenon in Indian forests (Ankila 2007). Damage due to forest fire is more severe in logged areas (Rowell and Moore 2000). Repeated burning in forests results in destruction of the ground flora and reduced vegetative growth rate leading to change in plant community structure (Spanos et al. 2010), changes in soil

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nutrient status (Certini 2005) and accelerated erosion (Inbar et al. 1998). Fire at the forest floor damages the cambium of the trees leading to the formation of defective butt logs and consequently, reducing timber quality (Marschall 2013). Fungal infections may occur through the damaged tissues. As a result of fire scars. Although Chir pine trees can withstand forest fire but the slit made in the tree trunk to collect resin enable the fire to burn the heartwood and kill the tree. Besides, emissions from forest fires viz. carbon dioxide, carbon monoxide, methane, hydrocarbons, nitric oxide and nitrous oxide cause serious health impacts and are also responsible for global warming (Koppmann et al. 2005). Forest fires in a nutshell have great impact on the land cover, biodiversity, forest ecosystem and climate.

Forest fire is considered as an important natural disaster under the Sendai framework for disaster risk reduction. It calls for a focused action within and across the sectors at regional, national and global levels. The actions include understanding the risk, strengthening the disaster risk management, investing in disaster risk reduction for resilience, enhancing disaster preparedness for effective response better recovery plans, rehabilitation and reconstruction (UNISDR/GE/2015—ICLUX EN5000 2015). The policy on fires in Indian forests has been existing since enactment of Indian Forest Act in 1927 in which causing forest fire is a punishable offence and it is mandatory for all forest dependent people to provide assistance in preventing and controlling fires. Unfortunately, it could not be implemented successfully for various reasons. The National Forest Policy 1988 also stressed upon forest protection against fire. Furthermore, it advocates the adoption of modern fire management practices for the prevention and control of forest fire. Indian states having good forest cover have been encouraged to adopt joint forest management program with community participation for controlling forest fire in accordance with the National Fire Prevention and Control guidelines 1999. As per Global Forest Resource Assessment, out of 67.5 million ha of Indian forests, about 55% of the forest cover i.e. 3.73 Mha of forests experience fire each year, causing an economic loss of over 440 crores of rupees apart from other ecological effects (Gubbi 2003). Thus, continuous mapping and monitoring are very important in the fire prone forests (Chand et al. 2006). Areas affected by the fires are frequently under reported (Hansen et al. 2010) which underestimates the damage.

Forest fire protection and control schemes emphasis on the adoption of modern techniques and equipment in the prevention and control of forest fires. Several studies demonstrate the use of satellite remote sensing based mapping, monitoring, and predictive modelling of forest fire (Jain et al. 1996) and significantly opens new doors to understand the causes, process and impacts of forest fire using geo-spatial technologies. From year 2007, National Remote Sensing Centre (NRSC) and later, Forest Survey of India has been disseminating fire signals on Real Time basis using MODIS fire alerts. The fire signals received from satellites are filtered, followed by value addition and communicated to State Forest Departments. Forest fire analysis reports are being shared with the states to help them in better management, improved preparedness and timely intervention by State Forest Departments in controlling forest fire and reducing damage arising out of it.

The paper has attempted to assess the vegetation damage caused due to the 2016 forest fire episode in the state of Uttarakhand. Burnt area assessment in the state is done at district level, forest administrative unit level, biodiversity level, for major forests types and protected areas. This study will help in understanding this fire episode and its spread which can be used for enhancing forest fire preparedness. It also throws light on the vegetation loss caused by forest fire.

Study Area

Uttarakhand has a total area of 53,483 km^2. It is situated between 28°43′N–31°27′N latitude and 77°34′E–81°02′E longitude in the north India (Fig. 1). It shares boundaries with Tibet and China in the north, Nepal in the east, Himachal Pradesh in the west and Uttar Pradesh district in the south. Lofty Mountains and rugged terrain represent 93% of the area in the state. The altitude ranges from 300 to 7816 m above MSL and the average rainfall of the state is 1523 mm. The wide variation in the topography has resulted in diverse ecosystems. The recorded forest area in the state is 24,240 km^2, which constitutes 45.32% of its total geographical area (SFR 2015). Broadly, Uttarakhand is divided into five major vegetation types. Above 4500 m, the Uttarakhand state is covered by ice, glaciers and rocky terrain. The western Himalayan alpine shrub and meadows lie between 3000 and 4500 m. The temperate western Himalayan subalpine conifer forests range between 2600 and 3000 m and form a tree line. Below 2600–1500 m, the temperate western Himalayan broadleaf forests occur. The Himalayan sub-tropical pine forests lie between 900 and 1500 m. The lower Himalayas or Upper Gangetic plains are covered by dry and moist deciduous forests. Dry savanna and grasslands cover the lowlands along the Uttar Pradesh which are also called Bhabhar.

The state also harbors rich diversity of fauna which includes 102 species of mammals, 600 bird species, 19 amphibian species, 70 reptiles and 124 species of fish. The above mentioned species, include globally endangered species such as tiger (*Panthera tigris*), Asian elephant (*Elephas maximus*), Alpine musk deer (*Moschus chrysogaster*), and vulnerable species such as Leopard (*Panthera*

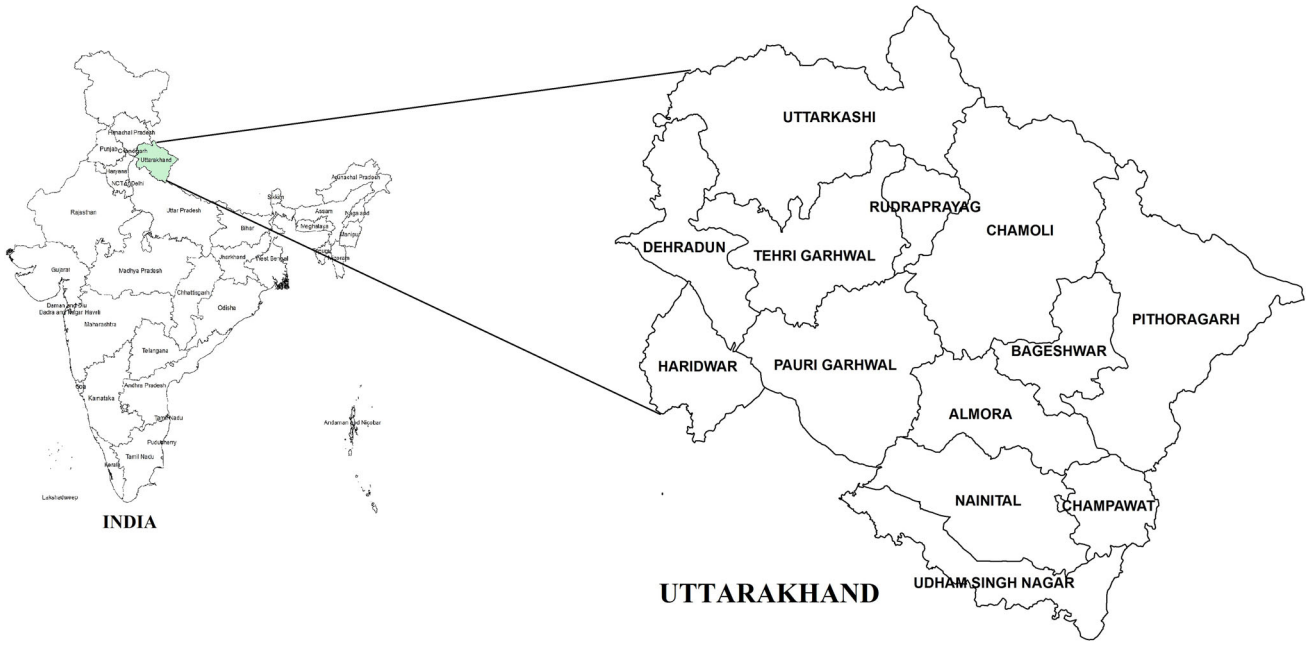

Fig. 1 Study area—Uttarakhand

pardus), Snow leopard (*Panthera uncia*) etc. (IUCN Red list 2017-3). There are six National Parks and six Wildlife Sanctuaries in the state which are home to rare plants and animals. The state also hosts three conservation reserves. Occurrence of forest fires is frequent in the state in the months of March–June. This causes loss to bio-resources, physical assets (in case it spread to the villages) and also affects the health of human, wildlife and the livestock.

Methodology

Ortho-rectified AWiFS satellite data acquired for the dates 23rd, 27th May and 2nd June, 2016 were used for mapping the burnt area. The satellite images were masked using forest type map to extract forest area. Further, the raster image of forest was classified using hybrid (Unsupervised and visual) classification method. The image was initially classified using k-means method of unsupervised classification. The burnt forest patches were distinctly seen in violet to black color in False Color Composite (FCC). SWIR, NIR and Red bands were used as the combination for FCC. Hence, the images were further delineated examining visually. Ground verification was carried out to corroborate the signature on the ground (Fig. 2). Accuracy assessment was carried out using random points generated over the state based on spectral signature and overall accuracy obtained was 84%. For assessing the extent of damage on different forest types and biodiversity regimes, forest type map and Biological richness map (Roy et al. 2012) were masked by the burnt areas and the results were analyzed using ArcGIS 10.1 and Erdas Imagine 2014. To know most affected administrative areas, forest division map, National parks boundary map and district maps were used. The biological richness of the state was mapped under a national level project of DoS–DBT at landscape level using vegetation type map derived using satellite remote sensing, phyto-sociological analysis in each vegetation type and information on the level of disturbance. The biological richness information from this project was also used to categorize different biological richness zones.

Results

The burnt area in the state of Uttarakhand during recent forest fires was found to be 3774.14 km^2, representing 15.28% of the total forest cover in the state. The detailed analysis of the burnt areas in terms of administrative units, vegetation type, biological richness and protected areas as follows.

Administrative Unit Wise Assessment

The cumulative burnt area map of the Uttarakhand between May 22 and June 3 2016 was 3774 km^2, shown in Fig. 3. Tehri Garhwal, Pauri Garhwal and Nainital are the worst affected districts in the state in terms of area. In terms of percentage, forest areas in districts of Almora, Bageshwar

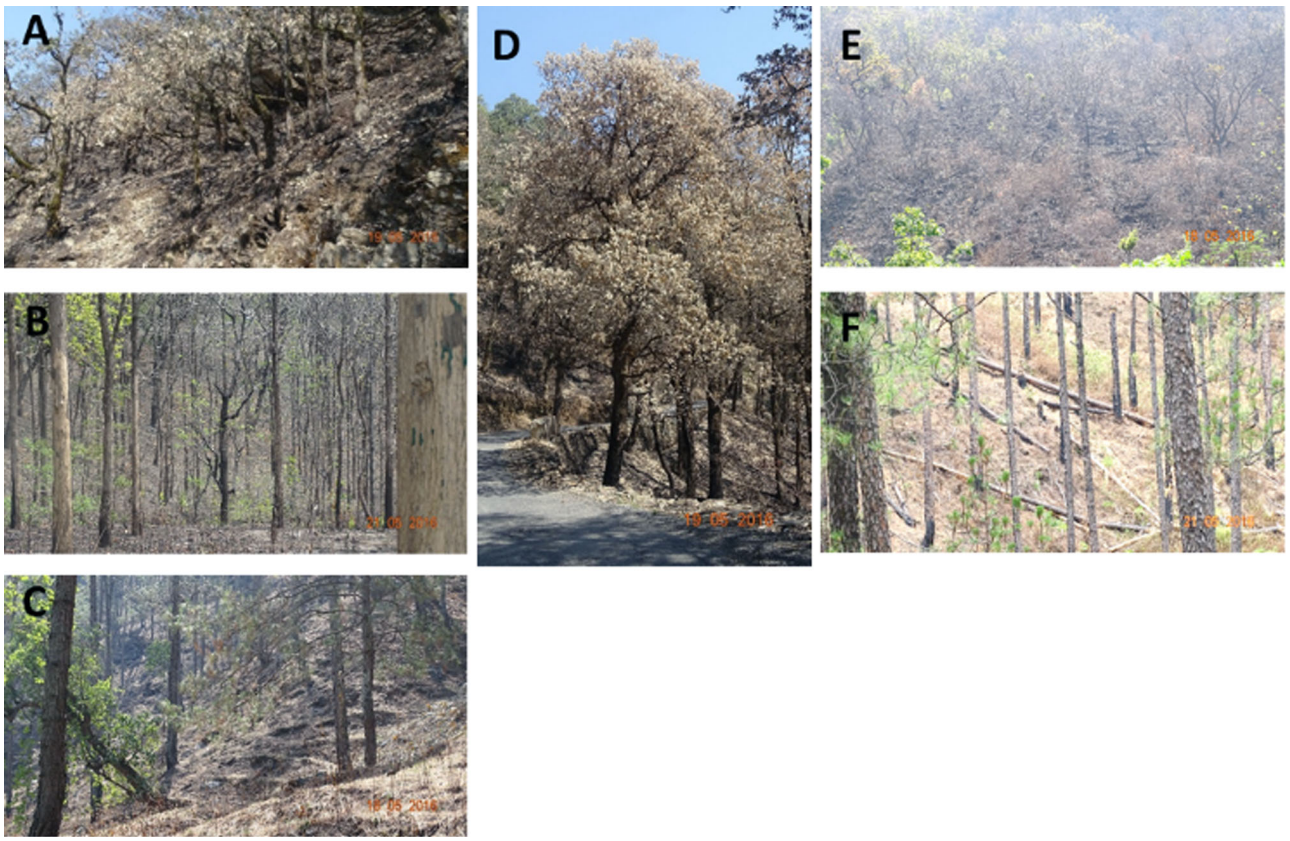

Fig. 2 Ground truth information on fire affected forest areas in the Nainital District of Uttarakhand. **a** Burnt patch of Dense Oak on the way from Pangot to Vinayak, **b** Sal Forest affected by Forest Fire near Ranibagh, **c** burnt patch of Dense Pine on the way from Bheemtal towards Padampuri, **d** showing a Burnt Oak Tree on the way from Pangot to Vinayak, **e** burnt patch of Dense Scrub on the way from Ranibagh to Bheemtal, **f** patch of pine affected by forest fire in Hairakhan (trees trunks severely damaged)

and Chapawat were most affected. The area of forest burnt was less on 23rd and 27th April but it almost doubled in all the districts by 2nd May. This day was also recorded as warmest day for Uttarakhand for the year 2016. The forest in the state of Uttarakhand is managed under 40 forest divisions. Of these, Lansdowne Forest Division, Pithoragarh Forest Division, Narendranagar Forest Division, Almora Forest Division, Champawat Forest Division, Nainital Forest Division, Bageshwar Forest Division and Garhwal Forest Division were worst affected divisions having burnt area ranging from 220 to 350 sq.km (Table 1). Uttarkashi Forest Division, Civil Soyam Almora, Kedarnath Wildlife Division, Rudraprayag Forest Division, Badrinath Forest Division, Tehri Forest Division and Lansdowne Forest Division are next in the ranking having burnt areas in the range of 90–170 sq. km in the same order. Remaining all divisions have area less than 90 sq km. and there has been almost no fire in the Nanda Devi Forest Division, Tarai West, East and Central Divisions and Soil Conservation Division in Kalsi. The percentage burnt area was maximum (24%) for Nainital Forest Division (Fig. 4).

Forest Type Wise Burnt Area Assessment

Forest type map has been shown in Fig. 5 and area affected due to fire is presented in Fig. 6. It shows that Pine forests are the ones which are most affected because of its high calorific value, presence of resin and ample amount of dry litter. A considerable area under the scrub, Himalayan moist temperate forests and moist deciduous forests has also burnt during the period.

Biological Richness Wise Burnt Area Assessment

An overlay analysis of the burnt area map and biological richness zones (Fig. 7) shows that 22.25, 12.73, 13.33 and 2.62% area belonging to low, medium, high and very high biological richness zones were caught in forest fire, respectively (Table 2).

Burnt Area Analysis for Protected Areas

Overlay analysis of the burnt area and the protected areas revealed that Corbett National Park, Rajaji Tiger Reserve/

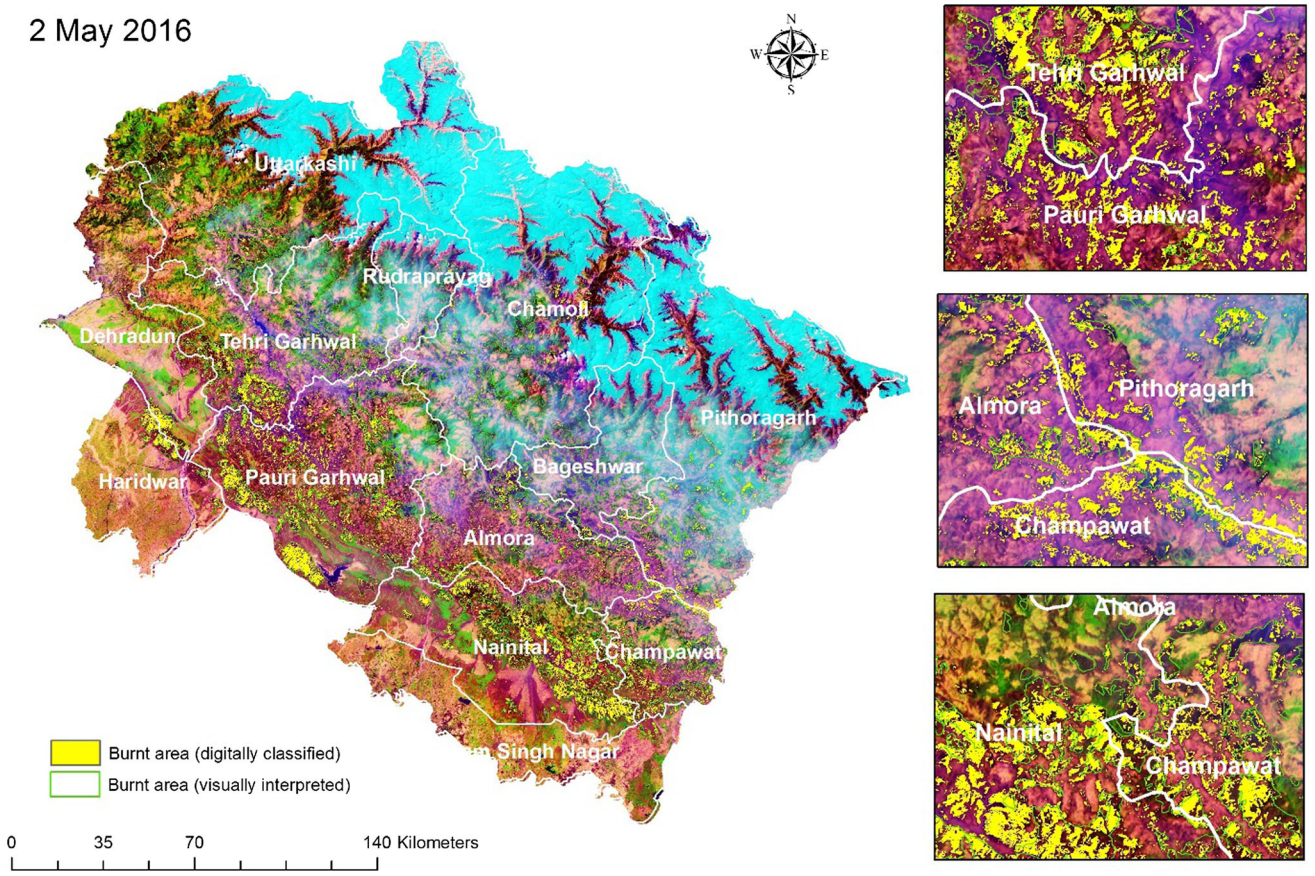

Fig. 3 Burnt area due to forest fires in the districts of Uttarakhand based on digital classification

Wildlife Sanctuary (WLS), Nandhuar WLS and Binsar WLS were the worst affected protected areas (Fig. 8). Askot Musk Deer and Sonanadi WLS were also affected up to 26 sq. km area (Table 3). Since animals die and migrate due to forest fire, post fire analysis on animals is recommended in the affected protected areas.

Discussion

Remote sensing over the last two decades has made great strides in terms of providing data to address operational and applied research questions beyond the scope and feasibility that ground-based studies can provide (Lentile et al. 2006). An account of increasing role of geo-informatics in reporting real time fire events of Uttarakhand forest fire has been given by Jha et al. (2016) which involved rapid assessment of active fire locations derived from Moderate Resolution Imaging Spectroradiometer (MODIS). They also estimated the burnt area in the state to be 2166.07 km^2. Earlier study stated that MODIS has underestimated total fire incident. Differences has been observed in fire data collected by state forest department and Forest Survey of India (FSI) (Singh et al. 2016) in Uttarakhand. MODIS capture only 5.64% of the fire incident while it was 19.04% recorded by forest department in Bageshwar Forest Division (BFD) and Chamoli forest division (CFD). The number of fire was 266 in BFD (2009–2014) and 126 in CFD (2006–2014) by state forest department, while it was 15 and 24 respectively, according to MODIS data. They attributed these differences to the coarse resolution of MODIS that failed to detect small fires of short duration particularly from dense forests. Thus, detailed account of post fire damage requires careful understanding of the spectral signatures and sufficient ground truthing for validation though the real time assessments using MODIS data gives a preliminary idea. The forest fire in the state of Uttarakhand is classified as high-frequency and low-severity surface fires of small size, which is largely determined by the moisture conditions of the pre-monsoon season (from March to mid-June) and the traditional practices of biomass collection by local people (Singh et al. 2016). We observed that this is primarily true in case of pine forests that stand tall with separate canopies whereas in case of the broadleaved forests of Oak and Rhododendron, these fires were sufficiently large and also damaged the crowns due to steep slopes. The burnt area assessment of the forests in the state as assessed in this study using

Table 1 Burnt area in different forest division in Uttarakhand

Name of division	Total divisions geographic area (km^2)	Total burnt area (km^2)	% Burnt area
Nanda Devi Forest Division	979.977	0	0.00
Tarai East Forest Division	1644.36	5.08956	0.31
Tarai West Forest Division	1034.75	3.80928	0.37
Tarai Central Forest Division	1135.3	4.7293	0.42
Haridwar Forest Division	1983.86	13.9068	0.70
Soil Conservation Division Kalsi	435.349	5.06693	1.16
Chakrata Forest Division	1222.08	20.3231	1.66
Dehradun Forest Division	867.61	14.7179	1.70
Upper Yamuna Barkot Forest Division	1030.23	21.2503	2.06
Tons Forest Division	761.415	22.4549	2.95
Uttarkashi Forest Division	2615.64	91.5424	3.50
Mussoorie Forest Division	803.369	31.3341	3.90
Pithoragarh Forest Division	6564.1	262.6	4.00
Ramnagar Forest Division	531.745	34.8522	6.55
Badrinath Forest Division	2179.76	167.913	7.70
Tehri Forest Division	2199.99	179.234	8.15
Haldwani Forest Division	418.891	40.7927	9.74
Kedarnath Wildlife Division	1064.15	108.992	10.24
Almora Forest Division	2345.79	283.217	12.07
Garhwal Forest Division	2856.35	354.121	12.40
Rudraprayag Forest Division	1193.82	157.288	13.18
Bageshwar Forest Division	2220.86	324.211	14.60
Civil Soyam Almora	586.986	96.0693	16.37
Lansdowne Forest Division	1308.67	220.076	16.82
Champawat Forest Division	1715.32	306.389	17.86
Narendranagar Forest Division	1183.17	265.893	22.47
Nainital Forest Division	1311.57	314.368	23.97

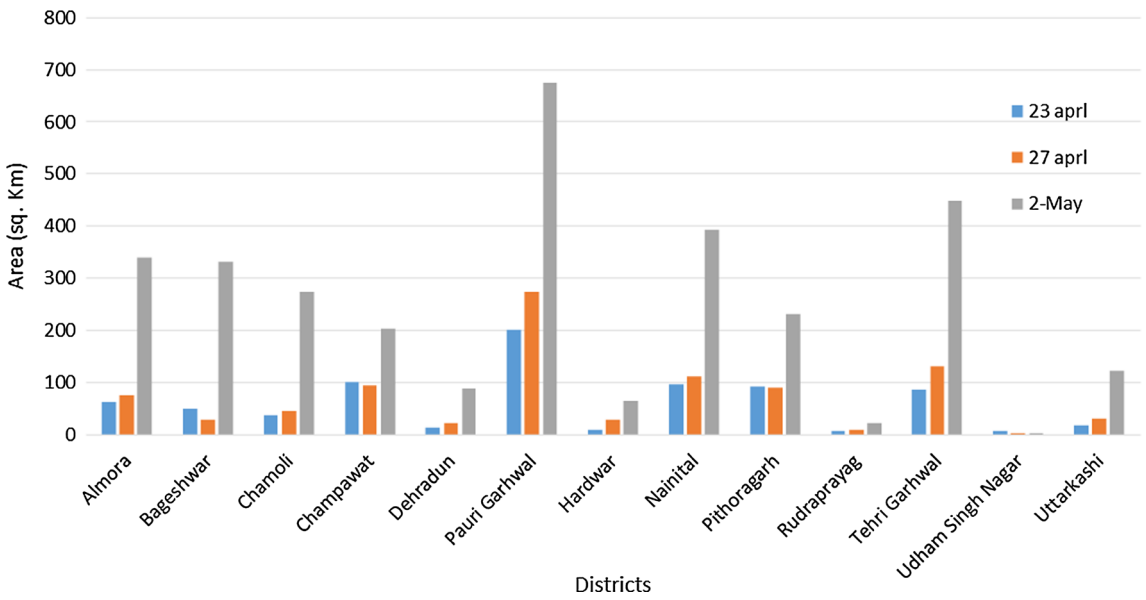

Fig. 4 Graphical representation of Date wise burnt area in different districts of Uttarakhand using digital extraction of burnt areas

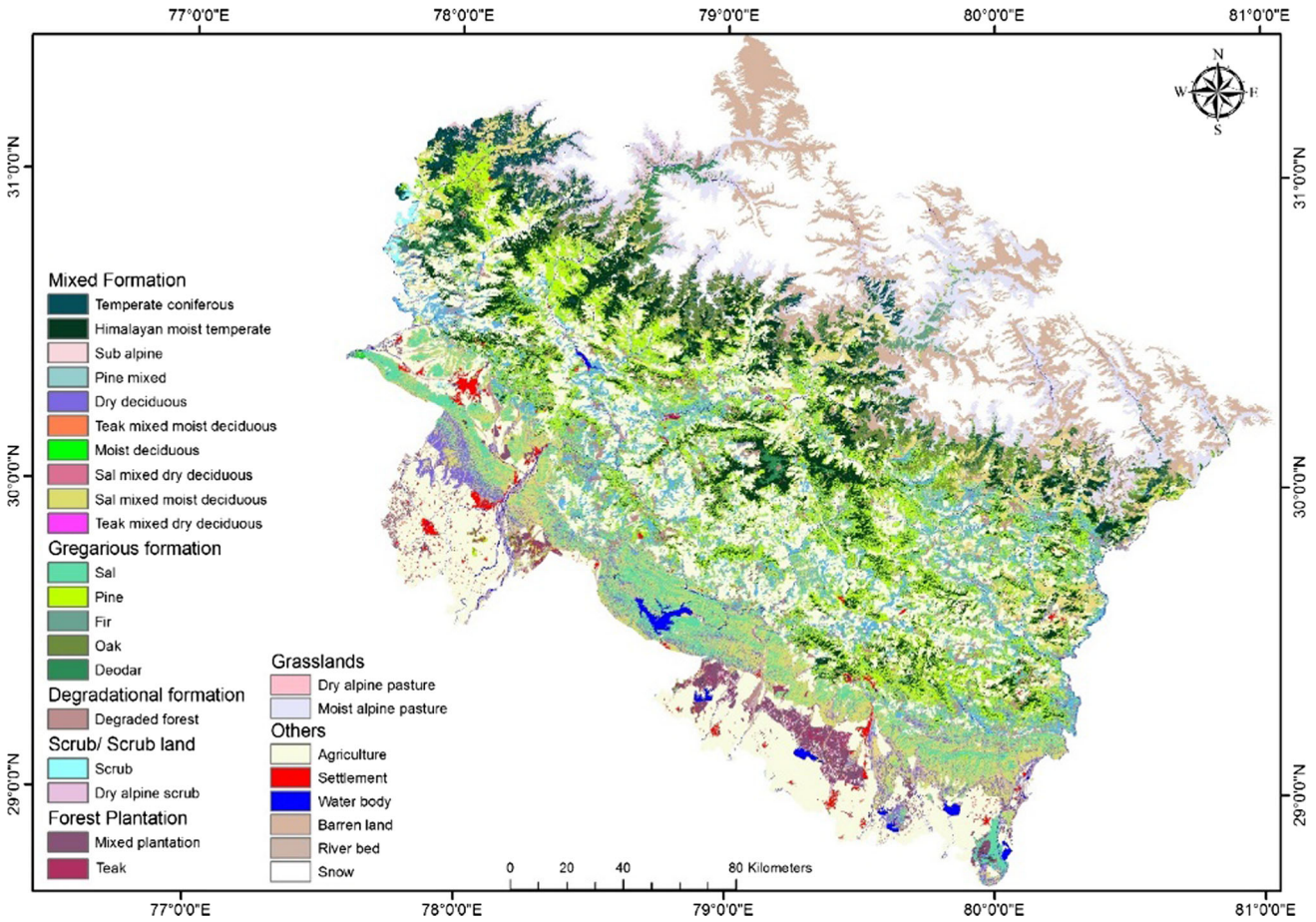

Fig. 5 Vegetation type map of the state of Uttarakhand

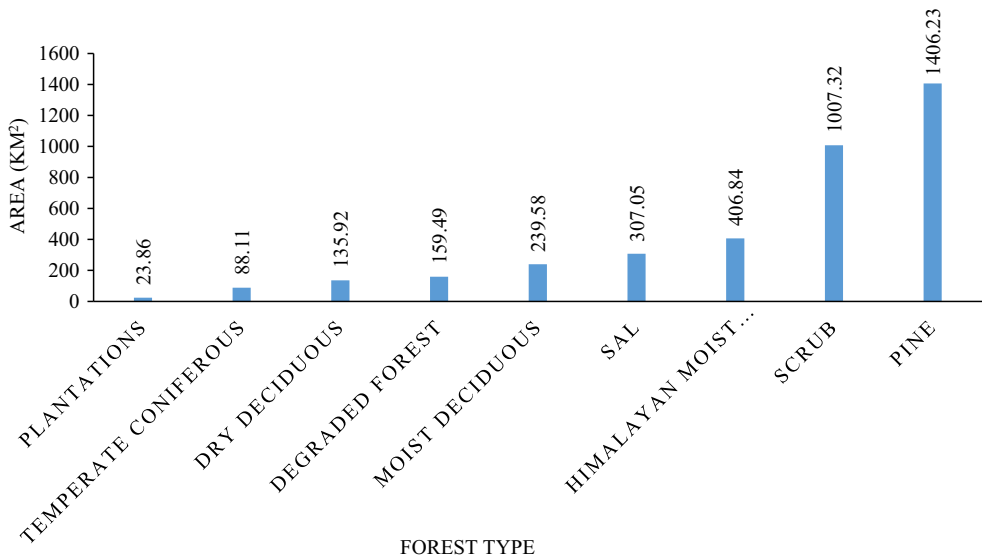

Fig. 6 Graph showing distribution of fire burnt areas in different forest types

AWiFS data of 56 m spatial resolution and ground validation was found to be 3774.14 km^2 representing 15.28% of the total forest area of the state, which seems more realistic in a given accuracy of 84%. Accurate assessment of burnt area assists in post-fire rehabilitation treatments, that are important in minimizing damage to soil, water and plant resources (Vallejo et al. 2000). Rehabilitation methods such as grass seeding, logging, building of branch

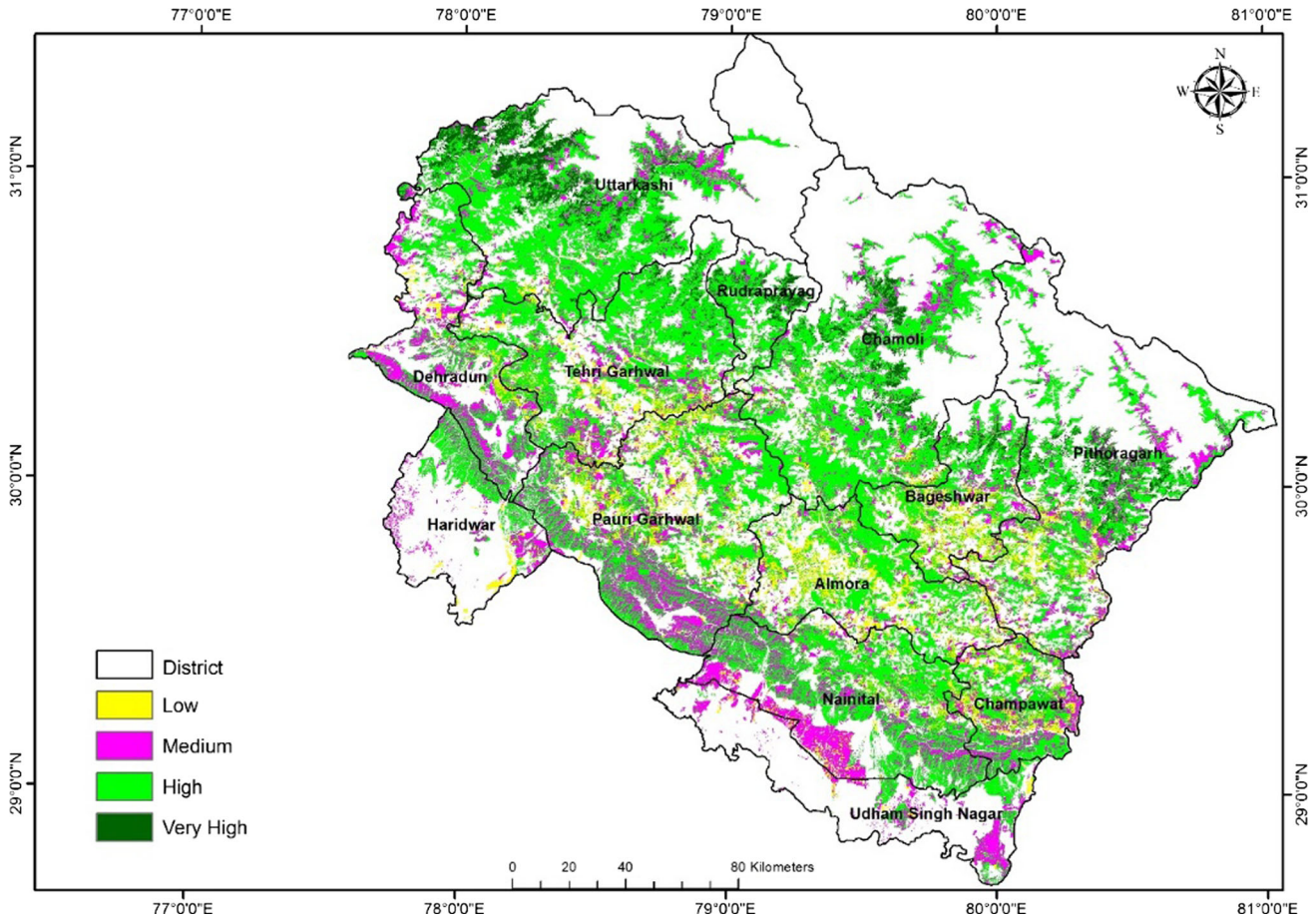

Fig. 7 Biological richness map of Uttarakhand

Table 2 Biological richness zone affected due to forest fire in Uttarakhand

Biological richness	Total geographical area (km^2)	Total bunt area (km^2)	% Burnt area in each zone
Low	2822.341434	673.23	23.85
Medium	5750.662	777.65	13.52
High	16,416.22604	2233.21	13.60
Very high	1698.869598	89.91	5.29
Total area	26,688.09907	3774.00	14.14

barriers and mulching may be used for replenishing the burnt forest areas (Robichaud 2000). The burnt area assessment in the biodiversity rich and protected areas identified in this study may be useful in mitigation planning to prevent drastic ecological impacts of the fires by monitoring in future to these intangible resources. The ecological impacts on productivity, regeneration and soil erosion etc. may be taken up in the mapped areas based on long term monitoring and measurements over gradients of fire vulnerable areas across the country. So far very little database is available and collected on systematic sampling protocols in forest fire. This limits the upscaling of measurements to regional and national context. There are also gaps in the assessment starting from the detection of fire to organizing preventive measures (Joseph et al. 2009). In order to have timely control of the fires, there is an increased need for early warning system based on state of art geo-informatics technology. Improved prediction of the forest fires using weather data acquired from Automatic Weather Stations (AWS) should be targeted in future. Participation of the citizens using crowdsourcing may also be encouraged, as it has the potential to provide contextual information that can provide alerts and ancillary information during the fires and in post-fire events.

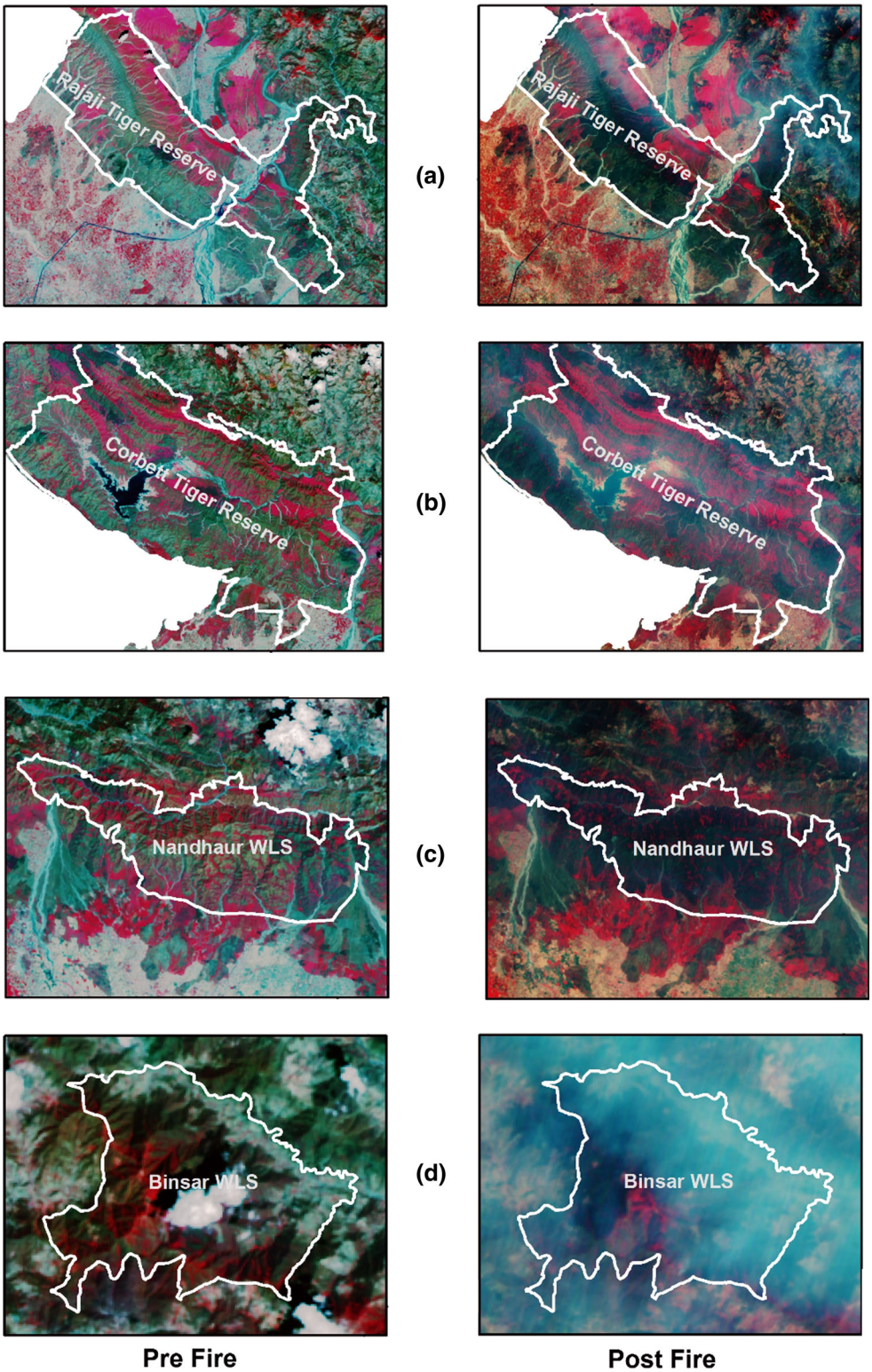

Fig. 8 Pre and Post fire images as seen on AWiFS satellite data during 2016 forest fire episode of Uttarakhand in **a** Rajaji Tiger Reserve, **b** Corbett Tiger Reserve, **c** Nandhuar WLS and **d** Binsar WLS

Table 3 Protected area wise burnt area in Uttarakhand

Sr. no.	Name of PA	Total geographic area (km^2)	Total burnt area (km^2)	% Burnt area
1.	Asan CR	4.18	0.03	0.61
2.	Askot Musk Deer WLS	599.93	21.54	3.59
3.	Benog WLS	10.82	0.00	0.00
4.	Binsar WLS	47.07	32.45	68.94
5.	Corbett National Park	520.82	6.45	1.24
6.	Corbett Tiger Reserve	1288.32	81.76	6.35
7.	Gangotri National Park	2390.02	0.00	0.00
8.	Govind National Park	472.08	0.00	0.00
9.	Govind Wildlife Sanctuary	485.89	1.81	0.37
10.	Jhilmil Jheel CR	37.84	0.07	0.17
11.	Kedarnath WLS	975.20	0.04	0.00
12.	Nanda Devi Biosphere Reserve	5148.57	0.00	0.00
13.	Nanda Devi National Park	624.40	0.00	0.00
14.	Nandhaur WLS	269.95	56.81	21.04
15.	Pawalgarh CR	5.82	3.75	64.51
16.	Rajaji National Park	820.42	192.52	23.47
17.	Sonanadi Wildlife Sanctuary	301.18	26.67	8.86
18.	Valley of Flowers	87.50	0.00	0.00

Conclusion

The satellite remote sensing along with proper ground truth and careful investigation of the spectral signatures make area assessment of the damage due to forest fire highly effective. The inputs generated in this study are shared with the state administrative authorities and the central parliamentary committee for a long term recovery plan.

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